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VERTICAL DISTRIBUTION OF ZOOPLANKTON IN CENTRAL EQUATORIAL PACIFIC, JULY-AUGUST 1952

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The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

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United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

VERTICAL DISTRIBUTION OF ZOOPLANKTON IN THE CENTRAL EQUATORIAL PACIFIC, JULY-AUGUST 1952

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Special Scientific Report: Fisheries No. 144

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VERTICAL DISTRIBUTION OF ZOOPLANKTON IN THE CENTRAL EQUATORIAL PACIFIC, JULY-AUGUST 1952

Longline-fishing surveys by the Pacific Oceanic Fishery Investigations (POFI) have shown a concentration of deep-swimming yellowfin tuna between the Equator and 5°N. latitude from 140° to 160°W. longitude (Sette 1954). This area is also relatively high in zooplankton abundance (King and Demond 1953), and it is believed that the concentration of both zooplankton and tuna within these latitudes is influenced by the increased fertility of the surface layer resulting from the equatorial upwelling of nutrient-rich water (Cromwell 1951, Sette 1954, and King[1/]).

In longline fishing in this region there has been a tendency for the deeper hooks, fishing at depths of about 300 to possibly 500 feet, to catch more tuna[2/] than the shallower hooks fishing at 150 to 250 feet (Murphy and Shomura, 1953a, 1953b). In the area of best catch, the deeper hooks apparently fish at about the level of the thermocline. One hypothesis immediately suggests itself: that these deep-swimming tunas are concentrating at the level which provides the most available food. It is known that the sharp temperature gradient associated with the thermocline may have a concentrating effect on certain plankton forms (Sverdrup et al. 1942, p. 794) and may restrict the migration of others (Moore et al. 1953).

The food of the yellowfin tuna consists of a great variety of organisms, both fish and invertebrates, varying widely in size (Reintjes and King 1953). Although zooplankton comprises on the average a very small percentage of adult tuna food, it is essential food of the forage fish, squid, and shrimp which are utilized directly by the tuna. Therefore, in sampling the zooplankton we believe we are obtaining a reliable index to the basic fish-food present in an area whether utilized directly or indirectly by the tunas.

Since the vertical distribution of zooplankton cannot be determined by the 200-meter oblique tow which has been used by POFI in surveying the relative abundance of zooplankton, a series of horizontal closing-net hauls was made with Clarke-Bumpus samplers (Clarke and Bumpus 1940) to investigate the vertical distribution of zooplankton in relation to the thermocline. Townsend Cromwell was field party chief on cruise 16 of the Hugh M. Smith on which these collections were made, and Heeny Yuen, field party member, was largely responsible for making the hauls. The figures were prepared by Tamotsu Nakata. The oceanographic data resulting from cruise 16 have been published (Austin 1954).

AREA AND METHODS

The sampling was done at 30 stations along 150°W. longitude extending from 12°N. to 7°S. latitude in the 9-day period, July 27 to August 4, 1952, on cruise 16 of the Fish and Wildlife Service vessel Hugh M. Smith. The approximate position of each station is shown in figure 1 and given more exactly together with the date, hour, and depth of hauling in table 1. Of the 90 hauls made, 68 are quantitatively usable. Improper functioning of the gear vitiated the remaining 22 hauls.

At each station, horizontal hauls were made simultaneously at three levels with Clarke-Bumpus samplers equipped with nets of 56XXX grit gauze having mesh apertures averaging 0.31 mm. in width. These were clamped on 5/32-inch (diameter) wire cable at intervals intended to place one sampler at a depth of about 200 meters during the haul, one at about the 70°F.

1/ MS. Variations in zooplankton abundance in the central equatorial Pacific, 1950-52. To be published in Proceedings of the Fifth Meeting of the Indo-Pacific Fisheries Council.

2/ Yellowfin, Neothunnus macropterus (Temminck and Schlegel); bigeye, Parathunnus sibi (Temminck and Schlegel); and albacore, Germo alalunga (Bonnaterre).

isotherm (which occurs within the thermocline in this region), and one just below the surface. A bathythermograph (BT) cast was made at each station before the plankton haul to determine the depth of the 70° F. isotherm. A 150-pound streamlined weight was attached to the end of the towing cable. The hauls were of about 1 hour's duration with a ship's speed of approximately 2 knots. The samples were preserved in 8 to 10 percent formalin neutralized with borax. The samplers were calibrated before and after the cruise, and the average of these calibrations was used to compute the cubic meters of water strained for each haul.

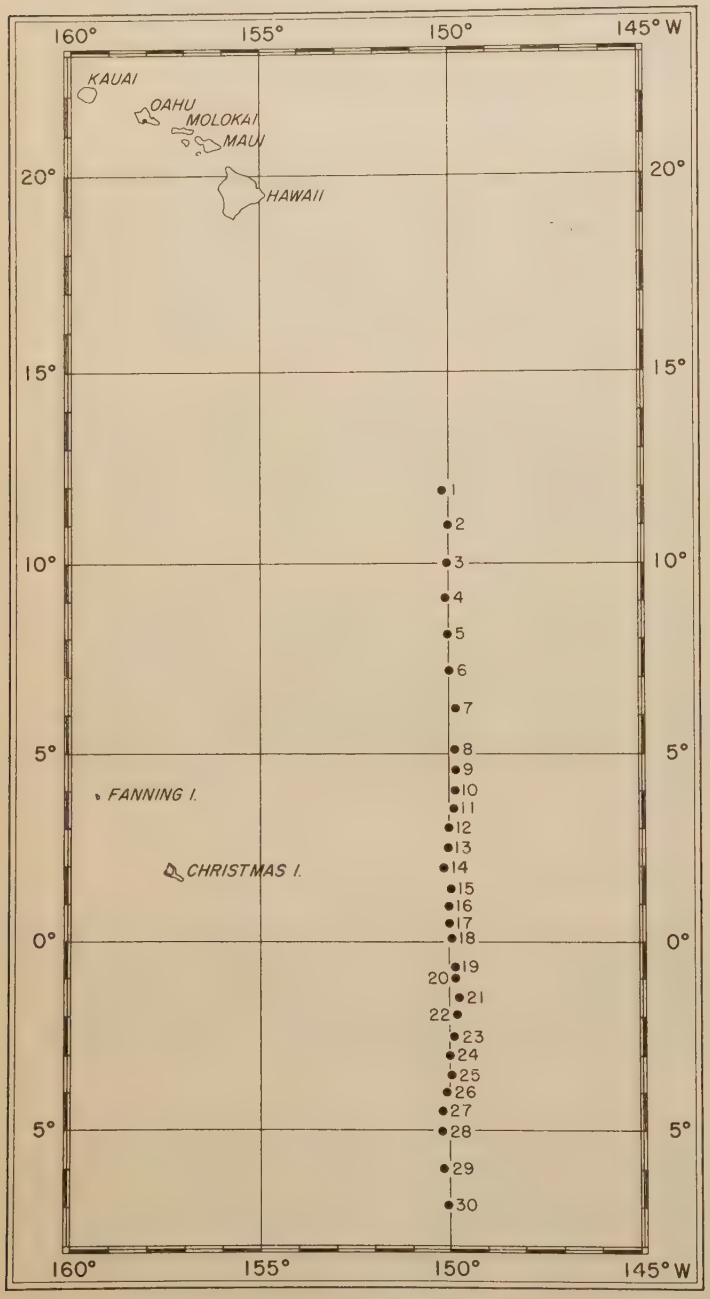

Figure 1.--Locations of stations 1-30 occupied by Hugh M. Smith, cruise 16, July-August 1952.

Estimating Sampling Depth

Throughout the cruise--for lack of exact information--the spacing of samplers on the towing wire was in accordance with the assumption that during the tow the wire described a straight line in the water; thus the cosine of the angle of stray of the towing wire from the vertical was used in calculating the amount of wire to pay-out to reach a desired depth. For example, anticipating a final wire angle of 60° and intending to have the middle sampler operate at the 70° isotherm located at 100 meters, the procedure would be: (1) attach the 150-pound weight to the end of the towing wire; (2) have the winch operator pay-out 10 meters of wire; (3) attach sampler No. 1; (4) pay-out 200 meters of wire; (5) attach sampler No. 2; (6) pay-out an additional 200 meters of wire; (7) attach sampler No. 3; (8) pay-out wire until the last sampler was just below the surface; (9) then begin the 1-hour tow, measuring the wire angle at 5-minute intervals and attempting to maintain a wire angle of about 60° by varying the vessel's speed.

In operating the samplers, however, it was found that the wire angle increased steadily with the increase in the amount of wire out and we doubted that the assumption of a straight wire provided a good estimate of the depth of the samplers. In order to obtain a closer approximation of the true sampling depth, four test hauls were made following the cruise essentially duplicating the procedure outlined above except

Table 1.--Estimated numbers and volumes of zooplankton collected on Hugh M. Smith cruise 16 using Clarke-Bumpus samplers (S = surface sample, I = intermediate sample, D = deep sample)

Station	Position		Date 1952	Time[1]	Sample	Depth, meters	Water strained, m^3	Zooplankton		
	Latitude	Longitude						No. /m^3	Vol., cc/ 1000m^3	Adj. sur. vol., cc/ 1000m^3
1	11°56'N.	150°09'W.	7/27	0506-0606	S	11	45.4	85	31.3	30.2
					I	125	29.5	107	36.3	--
					D[2]	--	--	--	--	--
2	11°00'N.	150°00'W.	7/27	1355-1500	S	10	38.2	221	43.5	58.3
					I	117	25.8	77	39.1	--
					D	260	28.5	29	7.7	--
3	10°01'N.	150°03'W.	7/27	2245-2345	S	6	42.7	172	74.9	52.6
					I	92	42.2	96	30.3	--
					D	185	38.9	50	8.5	--
4	09°05'N.	150°06'W.	7/28	0731-0831	S	8	39.8	167	43.2	51.8
					I	65	30.2	94	25.2	--
					D	223	36.3	43	12.7	--
5	08°06'N.	150°02'W.	7/28	1613-1714	S	10	25.0	394	81.9	92.5
					I	83	26.6	175	45.9	--
					D	257	41.1	24	12.9	--
6	07°08'N.	149°58'W.	7/29	0130-0212	S	8	19.5	329	98.3	72.3
					I	121	13.6	198	42.5	--
					D	223	35.2	57	20.2	--
7	06°10'N.	149°49'W.	7/29	1015-1115	S	8	34.1	368	62.8	87.9
					I	142	33.6	58	17.8	--
					D[2]	--	--	--	--	--
8	05°06'N.	149°51'W.	7/29	1942-2042	S	9	34.5	367	77.3	63.0
					I[2]	--	--	--	--	--
					D	225	42.2	45	12.3	--
9	04°34'N.	149°51'W.	7/30	0240-0340	S	9	29.6	353	85.5	66.4
					I	160	41.1	42	34.6	--
					D	230	41.0	36	14.6	--
10	04°02'N.	149°52'W.	7/30	0728-0828	S	9	29.2	313	52.3	62.5
					I	156	38.9	66	15.9	--
					D	233	50.4	84	25.2	--
11	03°32'N.	149°53'W.	7/30	1315-1415	S	10	32.7	221	28.1	38.9
					I[2]	--	--	--	--	--
					D[2]	--	--	--	--	--
12	03°02'N.	149°59'W.	7/30	1903-2003	S	9	27.0	584	89.5	76.9
					I	172	34.8	94	20.4	--
					D[2]	--	--	--	--	--
13	02°30'N.	150°02'W.	7/31	0050-0150	S	9	25.2	644	133.8	95.5
					I	152	34.8	88	31.0	--
					D	232	39.9	52	12.5	--
14	01°57'N.	150°07'W.	7/31	0642-0742	S	8	30.7	538	72.6	82.0
					I[2]	--	--	--	--	--
					D	215	42.0	65	24.5	--
15	01°24'N.	149°57'W.	7/31	1240-1340	S	8	27.7	344	50.9	72.0
					I	117	36.1	199	39.6	--
					D	215	47.2	92	25.4	--

[1] Zone time for 150° west longitude.
[2] No samples due to mechanical failure of samplers.

Table 1.--Estimated numbers and volumes of zooplankton collected on Hugh M. Smith cruise 16 using Clarke-Bumpus samplers (S = surface sample, I = intermediate sample, D = deep sample) (continued)

Station	Position		Date 1952	Time[1]	Sample	Depth, meters	Water strained, m^3	Zooplankton		
	Latitude	Longitude						No. /m^3	Vol., cc/ $1000m^3$	Adj. sur. vol., cc/ $1000m^3$
16	00°57'N.	150°01'W.	7/31	1753-	S	9	26.1	515	93.1	90.2
				1853	I	132	33.8	164	39.4	--
					D	243	44.6	77	26.4	--
17	00°28'N.	150°01'W.	7/31-	2332-	S	8	28.4	403	85.1	59.6
			8/1	0032	I[2]	--	--	--	--	--
					D[2]	--	--	--	--	--
18	00°06'N.	149°55'W.	8/1	0519-	S[2]	--	--	--	--	--
				0629	I[2]	--	--	--	--	--
					D[2]	--	--	--	--	--
19	00°39'S.	149°49'W.	8/1	1047-	S	8	21.6	273	51.9	73.8
				1147	I	127	38.8	258	44.3	--
					D	224	49.8	92	20.5	--
20	00°59'S.	149°50'W.	8/1	1509-	S	10	26.4	576	100.6	123.4
				1609	I[2]	--	--	--	--	--
					D[2]	--	--	--	--	--
21	01°28'S.	149°45'W.	8/1	2003-	S	9	18.7	722	121.2	96.4
				2103	I[2]	--	--	--	--	--
					D[2]	--	--	--	--	--
22	01°58'S.	149°48'W.	8/2	0133-	S	8	28.4	353	85.3	62.7
				0233	I[2]	--	--	--	--	--
					D[2]	--	--	--	--	--
23	02°29'S.	149°53'W.	8/2	0710-	S	7	30.0	266	47.4	55.2
				0810	I[2]	--	--	--	--	--
					D	191	49.8	58	27.1	--
24	02°59'S.	149°59'W.	8/2	1230-	S	6	30.0	204	20.7	29.2
				1330	I	99	41.7	288	41.0	--
					D	176	40.5	84	14.8	--
25	03°29'S.	149°57'W.	8/2	1752-	S	8	29.2	228	41.7	40.4
				1852	I	132	35.7	113	25.5	--
					D	211	34.2	68	12.9	--
26	03°59'S.	150°05'W.	8/2-3	2305-	S	8	23.9	300	37.3	26.1
				0005	I	144	41.6	100	24.5	--
					D[2]	--	--	--	--	--
27	04°29'S.	150°12'W.	8/3	0432-	S	6	28.2	285	36.2	33.0
				0532	I	116	46.3	126	22.3	--
					D[2]	--	--	--	--	--
28	05°02'S.	150°12'W.	8/3	0949-	S	9	25.3	279	24.5	33.9
				1053	I	176	31.3	100	7.7	--
					D[2]	--	--	--	--	--
29	06°00'S.	150°10'W.	8/3	1756-	S	6	29.1	239	49.9	48.3
				1856	I	147	53.5	94	20.6	--
					D	168	47.3	42	12.7	--
30	06°58'S.	150°05'W.	8/4	0209-	S	8	27.7	297	55.9	42.5
				0309	I	188	38.0	55	10.2	--
					D	225	37.4	31	7.0	--

1/ Zone time for 150° west longitude.

2/ No samples due to mechanical failure of samplers.

that a bathythermograph was attached just below the 150-pound weight to record depth and that the wire angle and wire out were measured at 1- to 2-minute intervals during each haul. From these measurements the approximate curvature of the towing wire on these four hauls has been reconstructed (fig. 2) by means of a series of triangles. If we assume that the wire maintains the same angle as it is lowered farther into the sea, then the sum of the vertical sides of the triangles should approximate the true depth attained under uniform current and ship speed. The pertinent data on the four test hauls are given in table 2. It is evident from this table that the method illustrated in figure 2 produces an estimate of the depth of hauling which is much closer to the depth recorded by the bathythermograph than the estimate based on the assumption that the towing wire conformed to a straight line.

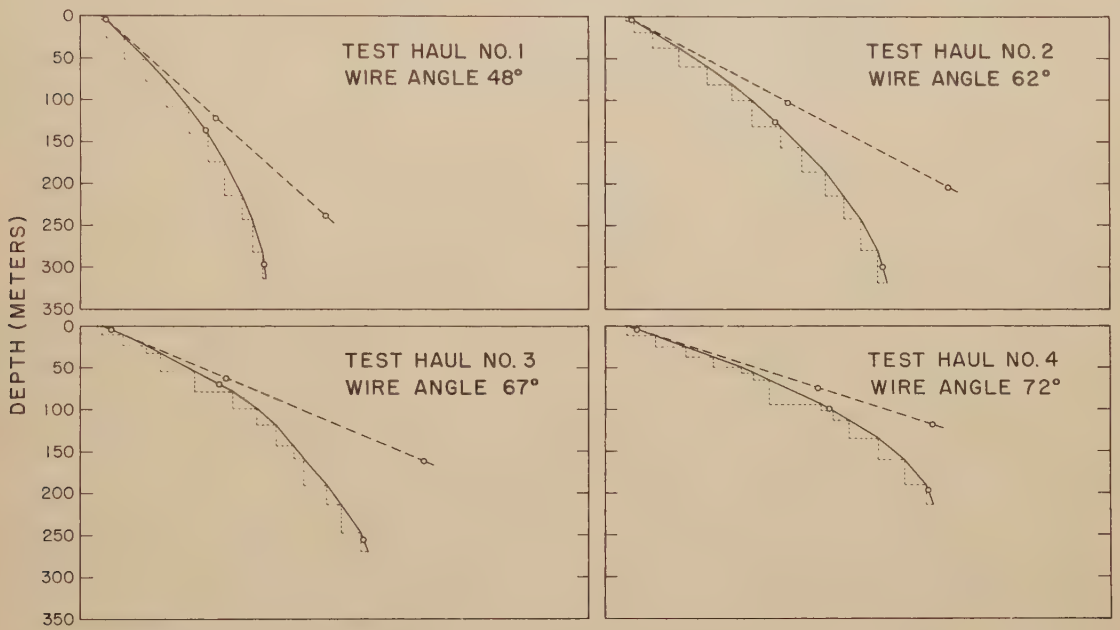

Figure 2.--Reconstruction of the curvature of the towing wire during four test hauls utilizing wire-angle and wire-out observations. Depths of the samplers assuming the towing wire to describe a straight line are shown for comparison.

The next step was to plot for the four test hauls the estimated depths calculated by the straight-line method against the estimated depths calculated by the curved-line method. On logarithmic graph paper the distribution appears to be rectilinear and a straight regression line was fitted as shown in figure 3. This line was then used to convert the straight-line estimated depths of cruise 16 to the equivalent curved-line estimated depths (given in table 1), using the maximum wire out and an average wire angle for the 1-hour haul. For example, if the estimated depth of the deep sampler on one of the hauls was 100 meters calculated by the straight-line method, the converted depth for that sampler would be 120 meters as derived from the graph in figure 3. When the converted depths are plotted in reference to the temperature structure, as in figure 4 and the selected bathythermographs of figure 5, it is apparent that the intermediate sampler was operating within the thermocline and usually between the 60° and 70° isotherms. The deep sampler was below 60° F.--with one exception (station 29)--and frequently below the 50° F. isotherm.

This method of estimation was necessary because wire out and wire angle were not recorded on cruise 16 while the samplers were being lowered but only during that portion of the haul when the samplers were open and fishing. This precludes direct estimation by the use of

Table 2.--Results of four test hauls showing differences in the estimated depth reached, employing three methods of determination

	Haul			
	1	2	3	4
Wire angle with full amount of wire out	48°	62°	67°	72°
Total wire out (meters)	370	450	427	431
Vertical height of work platform above sea surface (meters)	3	3	3	3
Length of wire between lead weight and deep sampler (meters)	10	10	10	10
Estimated depth of the deep sampler (meters):				
a. Assuming a straight wire	238	204	163	127
b. On curved-wire basis	294	300	257	197
c. As obtained from BT	293	301	239	204

triangles. However, it should be noted that in the waters traversed during this cruise there is marked horizontal shearing associated with differential current flows which undoubtedly exert a strong influence on the shape of the towing cable with its attached instruments. Under these conditions the actual depth of sampling will vary considerably from the estimated depth, especially when the latter has been derived from average relations. It is regretted that a continuous depth recorder was not available at the time of the cruise.

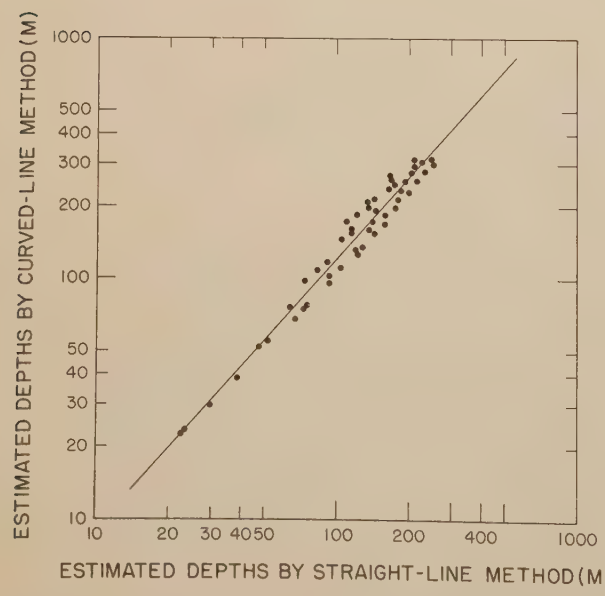

Figure 3.--Combined results of the four test hauls, plotted on a logarithmic scale, showing the relationship between estimated depths based on straight-wire and curved-wire calculations. The regression coefficient (b) = 1.1238.

Treatment of Samples in Laboratory

In the laboratory, displacement volume measurements were made on the 68 acceptable samples. First the few organisms with longest dimension greater than 2 cm. were removed from the sample, identified as precisely as possible, and their displacement volume measured. Then the volume of the remainder and bulk of the sample, i.e. those organisms with longest dimension less than 2 cm., was determined. In measuring the displacement volume, the plankton was poured into a draining sock of 56XXX grit gauze to filter off the preserving liquid. When the sample stopped dripping it was transferred to a graduated cylinder of appropriate size (usually 5 or 10 ml. capacity). By means of a burette a known volume of water was added to the drained plankton. The difference between the volume of the plankton plus the added liquid and the volume of added liquid was recorded as the displacement or net wet volume of that portion of the sample.

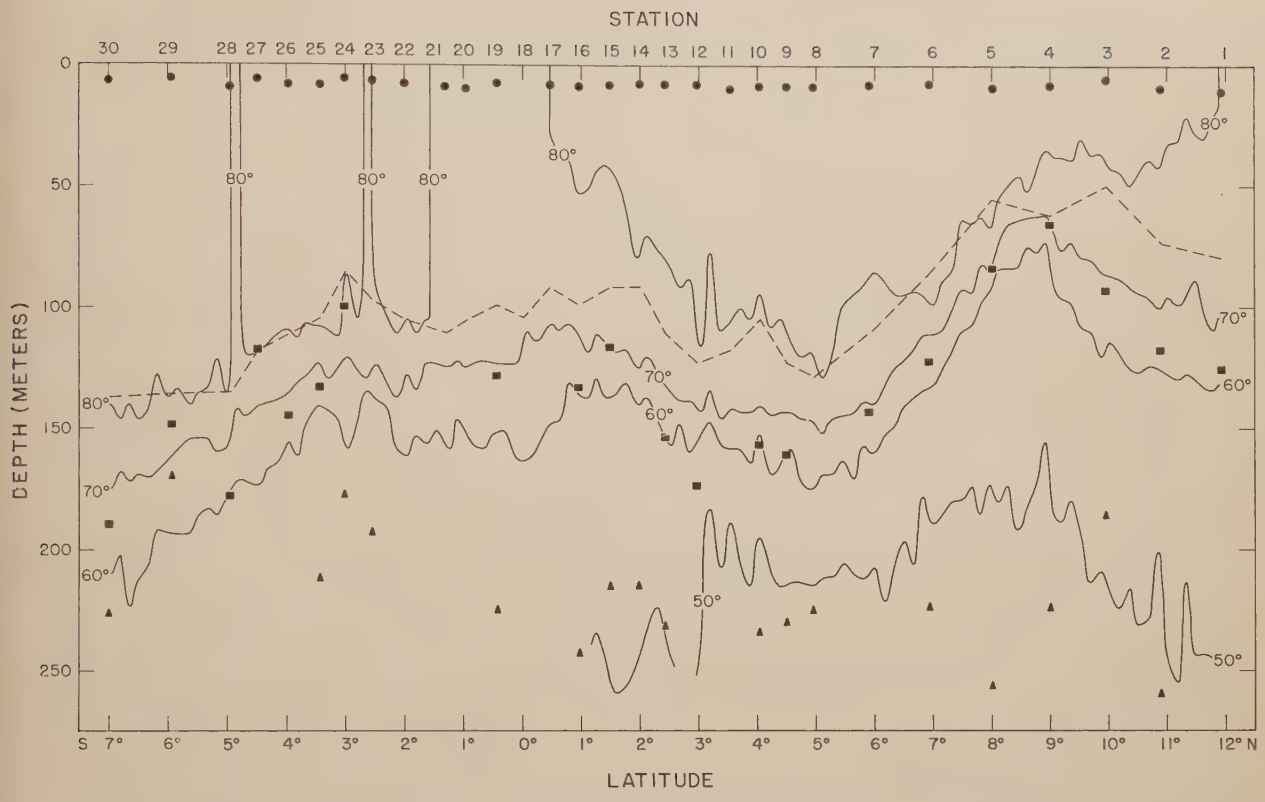

Figure 4.--Vertical temperature section along 150°W. longitude, showing the estimated hauling depths of the surface (●), intermediate (■), and deep samplers (▲) in relation to the temperature structure. The isotherms are derived from 900-ft. bathythermograph observations taken on stations 1 through 30 of Hugh M. Smith cruise 16, July-August 1952. The top of the thermocline is indicated by the dashed line.

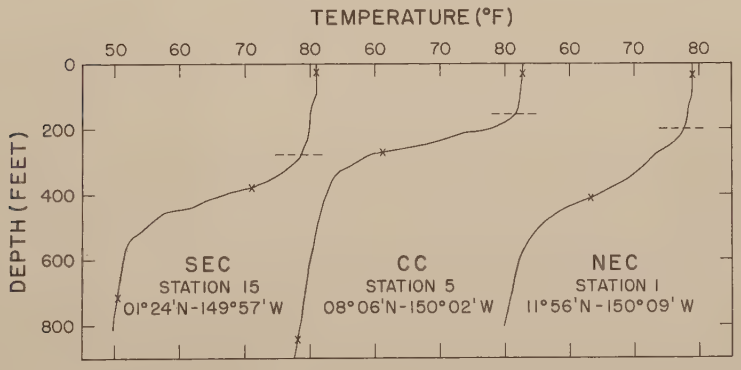

Figure 5.--Bathythermographs representative of the vertical temperature structure in the North Equatorial Current (NEC), the Countercurrent (CC), and the South Equatorial Current (SEC), at the station positions indicated. The hauling depths of the surface, intermediate, and deep plankton samplers are shown (X). A dashed line is drawn at the top of the thermocline.

Following the usual procedure at our laboratory, the volume of all organisms less than 2 cm. in length plus the volume of organisms 2 to 5 cm. in length that might be considered of significant nutritional value (such as the annelids, crustaceans, cephalopods and fish) were combined to give a single volume measurement for each sample. This figure was divided by the estimated amount of water passing through the net to give the volume of zooplankton per unit of water strained.

After the volume measurement the contents of each sample were spread out in a shallow rectangular dish (10 x 15 cm.). A Wolffhuegel counting plate was placed over the dish and all organisms greater than 0.2 mm.[3/] in their longest dimension were counted in 10 fields, each 1 cm. square. Organisms larger than 2 cm. had been previously removed from the sample and were counted separately. The counts of 12 major groups of the zooplankton, together with a miscellaneous category, including such things as annelids, shrimps, and fish, are given in table 3. An identification to species level was made of most of the organisms appearing in the six samples collected at stations 3 and 13. These results are given in table 4 and discussed in a later section (p. 14).

DIURNAL VARIATION

The importance of diurnal variation in estimating zooplankton abundance in the central Pacific has been discussed by King and Demond (1953) and King and Hida (1954). It was evident from initial examination of the volumetric data on which this report is based that the hour of hauling provided an important source of variation. This is demonstrated by the ratios of the average volumes of night hauls to day hauls, which were 1.63 for the surface samples, 0.90 for the intermediate samples, and 0.66 for the deep samples (table 5). When the data[4/] were examined by means of a "t" test, we found a highly significant ($P < 0.01$) difference between the volumes of day and night samples taken at the surface, a slight but nonsignificant ($P \simeq 0.5$) difference at the intermediate level, and a considerable, and nearly significant ($P \simeq 0.08$), difference at the deep level. Although the difference at the deep level may not be judged statistically significant, the fact that the observed volumes of the day hauls materially exceeded those of the night hauls at the deep level with just the reverse being true in the surface layer (table 5), suggests that there was some vertical migration taking place and that this marked day-night difference at the surface was not entirely the result of a simple dodging of the net. The lack of a strong day-night difference at the intermediate level suggests that this stratum received from layers below about as much plankton as it lost to layers above.

An adjustment to remove the effect of diurnal change in zooplankton volumes has been suggested by O. E. Sette, Director, Pacific Oceanic Fishery Investigations, and described by King and Hida (1954). The method is based upon the similarity between the diurnal variation in zooplankton abundance and the curve of the sine function with midnight equated to the angle whose sine is +1.0.

To examine the suitability of this method for correcting the day-night variation in the surface samples of cruise 16, the data were plotted as in figure 6, the abscissa being the sine function of the angle corresponding to the time of hauling. As the values have essentially a rectilinear distribution, a straight line was fitted as shown. The regression of the zooplankton volumes on the sine function is highly significant ($b = 0.1553$, $P < 0.01$). Following adjustment the night-day ratio is 0.98, as compared with 1.63 before adjustment, and the variance is reduced by one-third (table 6). From this evidence it appeared that the sine method of adjustment as devised for

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3/ It should be noted that this differs from the lower limit of 0.5 mm. used by King and Demond (1953) on plankton from hauls made by nets of coarser (30XXX grit gauze) mesh.

4/ Transformed by means of logarithms since the standard deviations of the untransformed data were proportional to the means.

Table 3.--Variations in numerical abundance (number[1/] of organisms per cubic meter of water strained) of 12 major groups of the zooplankton as sampled on cruise 16 of the Hugh M. Smith. (S = surface sample, I = intermediate sample, and D = deep sample)

Station	Sample	Foraminifera	Radiolaria	Siphonophora	Chaetognatha	Copepoda	Euphausiacea	Amphipoda	Ostracoda	Crustacean larvae	Gastropoda	Tunicata	Eggs	Miscellaneous
1	S	3	-	1	2	38	2	1	0	2	5	1	29	1
	I	-	-	1	4	76	2	0	6	2	1	6	6	2
2	S	3	0	1	16	184	0	3	0	1	3	3	4	4
	I	6	1	1	4	51	0	0	2	1	4	2	4	2
	D	5	0	0	0	19	1	0	0	0	0	0	2	3
3	S	12	0	3	5	132	5	3	1	0	6	1	2	1
	I	2	0	-	2	77	2	1	1	-	1	1	5	3
	D	2	1	-	2	38	-	0	-	-	1	-	5	-
4	S	19	0	2	8	120	-	1	0	1	8	3	1	2
	I	9	0	0	10	60	6	1	0	2	0	1	4	2
	D	0	1	0	1	31	1	0	3	-	0	1	3	2
5	S	14	0	0	6	330	0	0	0	4	4	23	11	2
	I	9	1	2	5	140	2	1	0	1	3	3	7	1
	D	-	-	0	-	17	2	0	2	0	0	0	2	1
6	S	27	0	2	7	234	2	1	1	4	18	22	9	3
	I	16	1	1	1	146	0	2	3	4	0	2	7	13
	D	4	-	-	1	36	-	0	6	0	-	-	4	6
7	S	29	5	-	7	249	2	-	0	5	4	21	41	4
	I	8	1	2	1	25	1	0	2	7	1	3	5	1
8	S	30	0	3	14	255	6	1	0	-	8	14	35	2
	D	6	2	-	1	17	0	-	5	0	4	-	8	1
9	S	36	0	5	8	217	2	-	0	2	15	9	57	-
	I	6	2	0	-	22	0	1	4	1	1	1	5	-
	D	2	6	0	2	16	0	-	2	2	0	0	6	0
10	S	57	1	0	8	164	7	0	0	4	10	9	53	-
	I	4	1	1	2	39	0	0	0	4	1	1	11	2
	D	3	2	-	1	59	2	0	4	0	3	1	7	2
11	S	32	1	0	4	119	-	-	0	2	6	7	49	0
12	S	32	0	2	16	434	13	1	0	3	13	19	50	1
	I	1	4	-	0	65	-	-	10	-	0	-	10	2
13	S	85	0	5	9	470	10	1	1	2	11	5	38	9
	I	13	-	-	1	49	1	0	7	0	-	2	6	7
	D	8	1	-	3	24	1	1	4	-	0	0	4	5
14	S	128	3	2	8	286	3	0	0	10	13	11	73	0
	D	2	-	-	2	31	12	1	5	1	1	0	9	1
15	S	101	2	0	3	195	0	-	0	0	-	13	27	1
	I	39	9	1	12	116	0	-	0	-	2	2	17	0
	D	6	13	-	3	56	1	-	7	1	-	-	4	-

1/ A zero indicates no organisms present; a hyphen indicates a count of less than 1 per cubic meter.

Table 3.--Variations in numerical abundance (number[1/] of organisms per cubic meter of water strained) of 12 major groups of the zooplankton as sampled on cruise 16 of the Hugh M. Smith. (S = surface sample, I = intermediate sample, and D = deep sample) (continued)

Station	Sample	Foraminifera	Radiolaria	Siphonophora	Chaetognatha	Copepoda	Euphausiacea	Amphipoda	Ostracoda	Crustacean larvae	Gastropoda	Tunicata	Eggs	Miscellaneous
16	S	41	2	2	6	372	3	-	0	3	10	23	49	3
	I	30	3	-	6	86	4	-	1	5	3	-	24	1
	D	4	7	0	1	45	1	0	8	3	1	-	5	-
17	S	48	-	3	7	263	10	-	0	0	17	23	31	0
19	S	76	6	1	4	136	2	0	1	1	0	33	11	1
	I	79	3	2	19	136	0	1	-	-	5	1	10	1
	D	8	9	1	-	39	6	-	2	0	2	0	24	1
20	S	32	15	4	4	319	6	0	0	8	1	50	136	0
21	S	117	5	4	14	415	2	2	0	23	30	40	69	2
22	S	32	9	2	8	176	2	1	0	5	15	12	90	1
23	S	63	2	2	2	126	3	0	-	4	2	6	56	-
	D	3	2	0	1	32	-	0	5	1	4	-	7	2
24	S	30	4	0	2	118	5	0	0	-	7	15	22	0
	I	29	5	0	6	172	0	0	-	2	44	3	24	1
	D	2	4	0	1	53	0	0	7	2	3	3	11	0
25	S	20	2	-	2	170	1	-	0	2	1	12	16	0
	I	8	2	0	3	80	2	0	6	1	1	-	9	-
	D	1	4	0	3	45	0	0	2	2	0	3	6	2
26	S	18	0	1	11	266	1	0	1	0	0	1	0	0
	I	9	-	0	6	72	-	0	9	0	1	-	2	-
27	S	22	-	-	6	230	1	0	1	0	9	3	12	0
	I	24	0	-	5	82	2	0	1	2	-	1	8	1
28	S	33	1	1	3	179	0	0	0	5	0	30	27	1
	I	10	1	-	2	62	0	-	2	1	0	1	19	-
29	S	21	0	1	4	157	-	0	0	1	15	13	25	-
	I	16	2	0	2	49	2	-	3	3	6	1	10	-
	D	2	-	-	0	27	1	0	7	0	0	-	3	1
30	S	14	-	1	7	201	1	0	-	4	44	11	14	-
	I	4	5	-	1	31	1	-	9	1	0	0	2	2
	D	-	2	0	-	21	0	0	4	1	1	-	1	0

1/ A zero indicates no organisms present; a hyphen indicates a count of less than 1 per cubic meter.

Table 4.--Partial list of organisms occurring in samples collected at stations 3 and 13 of Hugh M. Smith cruise 16, with the general estimated abundance classified as present (x), frequent (xx), very frequent (xxx), and conspicuously abundant (xxxx). Both stations were occupied at night

Organisms	Station 3 10°01'N.-150°03'W. N. Equatorial Current			Station 13 02°30'N.-150°02'W. S. Equatorial Current		
	Surface sample	Interm. sample	Deep sample	Surface sample	Interm. sample	Deep sample
Copepoda						
Calanoidea						
Euchaeta prestandreae (Philippi)	xxx	xxxx	xx	xx	xx	--
Pleuromamma abdominalis (Lubbock)	--	xx	--	xxxx	x	--
Pleuromamma robusta (Dahl)?	--	--	--	--	x	--
Pleuromamma xiphias (Giesbrecht)	x	--	--	x	--	--
Candacia pachydactyla (Dana)	x	x	--	xx	--	--
Neocalanus gracilis (Dana)	xxx	x	--	xxx	xxx	--
Rhincalanus cornutus (Dana)	--	x	--	--	x	xxxx
Calanus minor (Claus)?	--	xxxx	--	--	--	--
Eucalanus attenuatus (Dana)	x	x	x	xxx	xxxx	--
Heterorhabdus spinifrons (Claus)	--	--	xx	--	x	--
Phyllopus bidentatus (Brady)	--	--	--	--	--	xx
Metridia longa (Lubbock)	--	--	--	x	--	x
Scottocalanus securifrons (T. Scott)	--	--	--	--	x	--
Scolethrix danae (Lubbock)	--	--	x	x	--	--
Undeuchaeta sp.	--	x	--	--	--	--
Undeuchaeta major (Giesbrecht)	--	--	--	--	x	x
Bradyidius armatus (Brady)?	--	--	--	--	x	--
Undina vulgaris (Dana)	xx	--	--	--	--	--
Cyclopoidea						
Oncaea sp.	xx	xxx	x	xxx	x	xxx
Oithona sp.	xx	xx	--	--	x	--
Corycaeus sp.	x	xxx	x	xxx	x	xx
Saphirinella stylifera (Lubbock)	--	--	--	x	x	--
Copilia mirabilis (Dana)	--	--	--	x	x	--
Saphirina scarlata (Giesbrecht)	--	--	--	x	--	--
Saphirina metallina (Dana)	--	x	x	--	--	--
Harparticoidea						
Aegisthus mucronatus (Giesbrecht)	--	--	--	--	--	xx
Microsetella rosea (Dana)	--	x	x	--	--	--
Euphausiacea						
Euphausia sp.	--	--	x	--	--	--
Euphausia diomedeae (Ortmann)	xx	x	--	xx	x	--
Stylocheiron sp.	--	x	x	--	--	--
Amphipoda						
Primno latraillei (Gosse)?	--	--	x	--	--	--
Phronima sp.	--	x	--	--	--	--
Phronimella elongata (Claus)	x	--	--	x	--	--
Cyphocaris micronyx (Stebbing)	--	--	--	--	--	x
Hyperia luzoni (Stebbing)	--	--	--	x	--	--
Letocotis ambobus (Stebbing)	x	--	--	--	--	--
Anchylomera blossevillii (Milne-Edwards)	--	x	--	--	--	--
Decapoda						
Lucifer reynaudii (Milne-Edwards)	--	--	--	x	--	--

Table 4.--Partial list of organisms occurring in samples collected at stations 3 and 13 of Hugh M. Smith cruise 16, with the general estimated abundance classified as present (x), frequent (xx), very frequent (xxx), and conspicuously abundant (xxxx). Both stations were occupied at night (continued)

Organisms	Station 3 10°01'N.-150°03'W. N. Equatorial Current			Station 13 02°30'N.-150°02'W. S. Equatorial Current		
	Surface sample	Interm. sample	Deep sample	Surface sample	Interm. sample	Deep sample
Chaetognatha						
Sagitta sp.	--	x	x	xx	--	x
Pteropoda						
Cymbulliopsis sp.	--	x	--	--	--	--
Heteropoda						
Atlanta sp.	--	--	--	x	x	--
Fish						
Vinciguerria lucetia (Garman)	--	--	--	--	x	--

Table 5.--Average volumes and night/day ratios of zooplankton collected by Clarke-Bumpus samplers on cruise 16 for 3 depths of sampling (twilight hauls omitted)

Depth	Time of hauling	No. of samples	Ave. volume, cc/1000m^3	Ratio, N/D
Surface	Night	11	85.2	1.63
	Day	13	52.3	
Intermediate	Night	7	27.6	.90
	Day	9	30.7	
Deep	Night	6	12.5	.66
	Day	9	19.0	

Table 6.--Certain statistics showing the mean volumes and extent of variation for the surface, intermediate, and deep hauls

	Surface		Intermediate	Deep
	Adjusted	Unadjusted		
Number of samples (n)	29	29	21	18
Mean volume ($\bar{x}$)	62.7	64.7	29.2	16.6
Variance (s^2)	581.4	850.7	129.9	46.2
Standard deviation(s)	24.1	29.2	11.4	6.8
Coefficient of variation (C), as percent	38.5	45.1	39.0	41.0

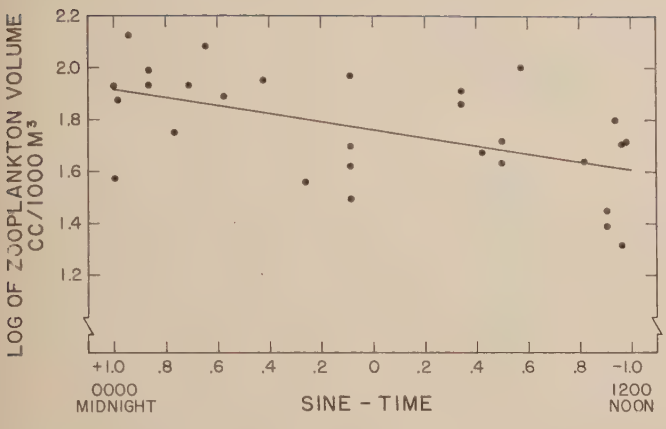

Figure 6.--Logarithms of zooplankton volumes of Hugh M. Smith cruise 16 plotted against the sine value corresponding to the hour of hauling, and showing the calculated regression line for the relationship.

the 200-meter oblique hauls provided a means for approximately removing the diurnal variation in this group of surface samples. This method of adjustment was not considered applicable to the intermediate samples where there was almost no day-night difference nor to the deep samples where there may be a difference but in a direction opposite to that at the surface.

The numerical data show essentially the same diurnal variation in zooplankton abundance as the volume data, although statistically the day-night difference must be considered nonsignificant (since $P > 0.05$) at all three levels. Table 7 gives the night-day ratios based on numbers of organisms for the total samples and for Copepoda, the major constituent. Although the differences are not significant, the ratios suggest that more zooplankton was captured at the surface at night than in the day time, with just the reverse being true for the intermediate and deep levels.

VARIATIONS WITH DEPTH AND LATITUDE

The average volumes for the three sample depths, surface (adjusted for hour of hauling), intermediate, and deep, were 62.7, 29.2, and 16.6 cc/1000m^3 respectively (table 6). The corresponding variances were 581.4, 129.9 and 46.2. Since most of the variation in the surface volumes related to hour of sampling had already been removed, the chief sources of variation remaining are those associated with latitude, depth, and sampling error.

When the zooplankton volumes (transformed by means of logarithms) are subjected to an analysis of variance with 2-way classification, we find significant differences ($P < 0.05$) among stations (latitudes) and highly significant differences ($P < 0.01$) related to the depth of sampling. In respect to latitude, the area of best catch, particularly for the surface samples, extended from approximately 2°S. to 8°N. (fig. 7A). About the same degree of variation with latitude is evident at all three depths. Although there was no marked indication of increased abundance immediately at the Equator, the largest single volume was taken at the surface at about 1°S. latitude.

Table 7.--Average numbers and night-day ratios of total zooplankton and of Copepoda as obtained in the Clarke-Bumpus hauls of cruise 16 for 3 depths of sampling (twilight hauls omitted)

Depth	Time of hauling	Number of samples	Total zooplankton		Copepoda	
			Ave. number per m^3	Ratio N/D	Ave. number per m^3	Ratio N/D
Surface	Night	11	411.1	1.28	278.3	1.43
	Day	13	320.2		194.2	
Intermediate	Night	7	96.0	0.66	66.0	0.74
	Day	9	146.0		89.1	
Deep	Night	6	45.1	0.71	25.3	0.68
	Day	9	63.4		37.4	

With only two exceptions (stations 1 and 24, at latitudes 12°N. and 3°S.) the largest volumes were found among the surface samples. There was no evidence of a concentration of zooplankton in the region of the thermocline. The apparent greater abundance of deep-swimming tuna at this depth cannot, therefore, be explained on this basis. Information on the abundance of the intermediary forage organisms, which have not as yet been sampled quantitatively, and their grazing effect on the zooplankton are needed if we are to fully understand the complex interrelationship that exists.

The plankton counts demonstrated the same general variation with latitude and depth as was found for the volumes (fig. 7B). Figure 8 illustrates the variation in numbers of organisms with latitude and depth for eight of the major zooplankton groups. Although there is considerable station-to-station variation--partly due to differences in the hour of sampling--the figure shows that, for most groups, the largest numbers were found at the surface and in the general region of the Equator. This is particularly well demonstrated by the Copepoda, Foraminifera, eggs (mostly invertebrate), and Tunicata. The other groups shown on figure 8 were present in relatively small numbers and do not provide as definite conclusions.

Another variation related to depth and hour of hauling is that of size of organism. A rough estimate of average size (volume) for the constituents of each sample was obtained by dividing the displacement volume of the sample by the estimated number of organisms. The results, summarized in figure 9, show an increase in average size with depth. Disregarding time of hauling, the means for the three sampling depths--surface, intermediate, and deep--were 2.0, 2.7, and 3.0×10^{-4}cc., respectively. These were found to be significantly different ($P < 0.05$) when examined by means of an analysis of variance.

When the data are segregated into day, night, and twilight hauls, we find some suggestions that the mean size of the zooplankton was greater at night than in the day at the surface and intermediate levels, but the opposite was true at the deep level (fig. 9). It is possible that the relatively large organisms captured in the day hauls at the deep level swam upward at night to be taken in the night hauls at the intermediate level, but most of this group, apparently, never reached the surface. The presence of larger organisms in the night hauls than in day hauls at the upper two levels is possibly the result of upward movement of larger organisms from deeper layers in the case of the intermediate depth, but dodging of the net in the daytime could also be involved, especially at the surface level.

COMPOSITION OF THE ZOOPLANKTON

The great variety of organisms making up the collections is characteristic of tropical zooplankton populations as contrasted with the larger volumes but relatively few species which are typical of temperate and boreal waters. The Copepoda were the most abundant group in actual numbers in all samples (table 3). The similar importance of copepods in 1-meter net collections from the central Pacific was previously noted by King and Demond (1953). Next in order of numerical abundance were the Foraminifera (mostly Globigerina and Globorotalia), eggs (mostly invertebrate), Tunicata (mostly Appendicularia), Gastropoda (mostly Pteropoda and Heteropoda), Chaetognatha, Radiolaria, crustacean larvae, Ostracoda, Euphausiacea, Siphonophora, and Amphipoda. Average numbers per cubic meter and percentage composition, by major constituents, of the zooplankton are summarized by depth for the entire cruise in table 8. While most groups decreased in absolute number with depth of sampling, the Ostracoda showed a small but consistent increase with depth. The Radiolaria also averaged greater in number in the deep samples than at the surface and intermediate levels. With respect to percentage composition, the Copepoda and Tunicata became relatively less important with increased depth of sampling, while Ostracoda, Euphausiacea, and Amphipoda consistently gained in relative importance with depth. The percentages for the remainder of the groups varied in irregular manner or were approximately the same at all three depths.

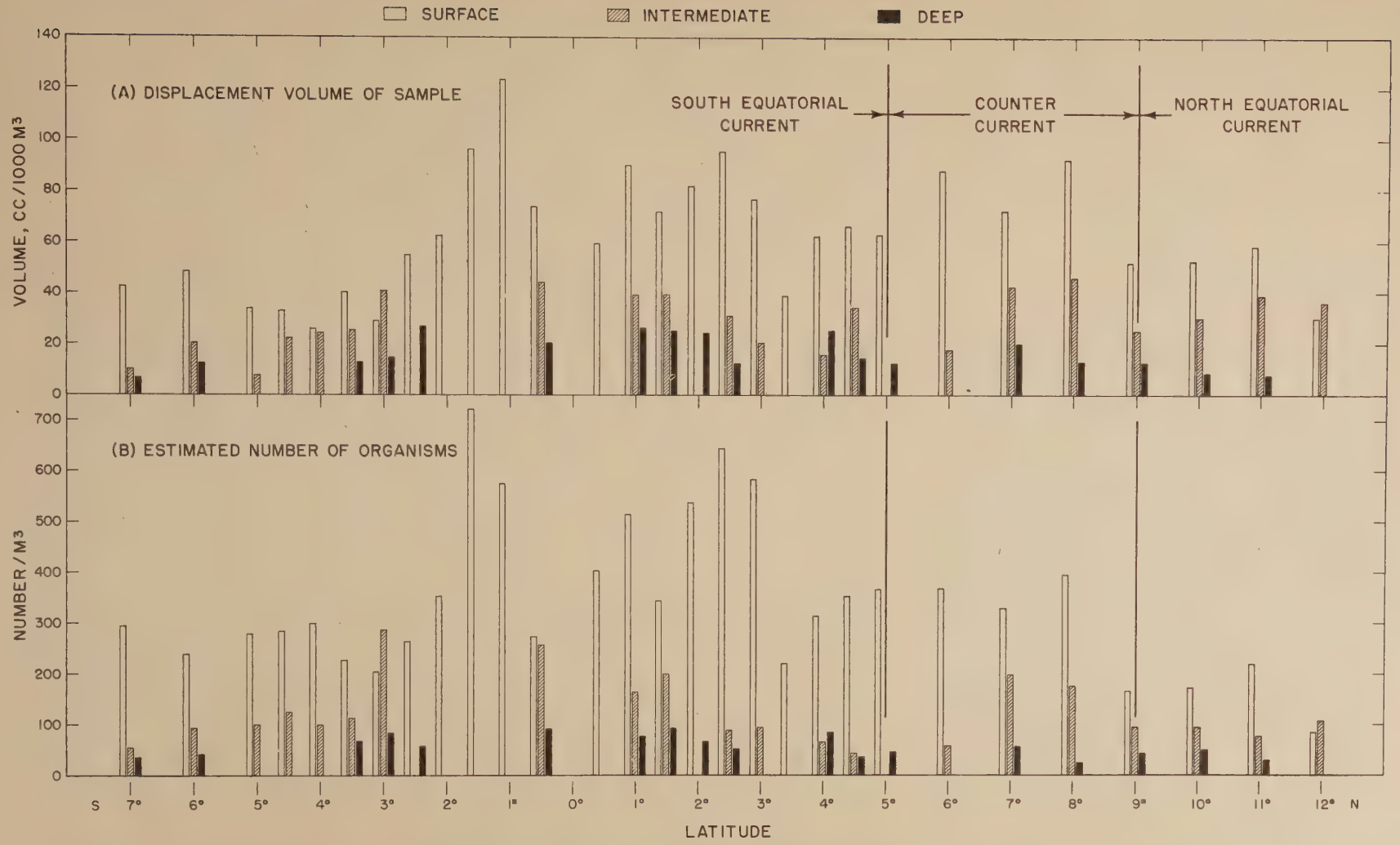

Figure 7.--Variations in the horizontal and vertical distribution of zooplankton as measured on Hugh M. Smith cruise 16.
A.--Displacement volumes of samples. The surface volumes have been adjusted for differences related to the hour of hauling.
B.--Estimated numbers of organisms.

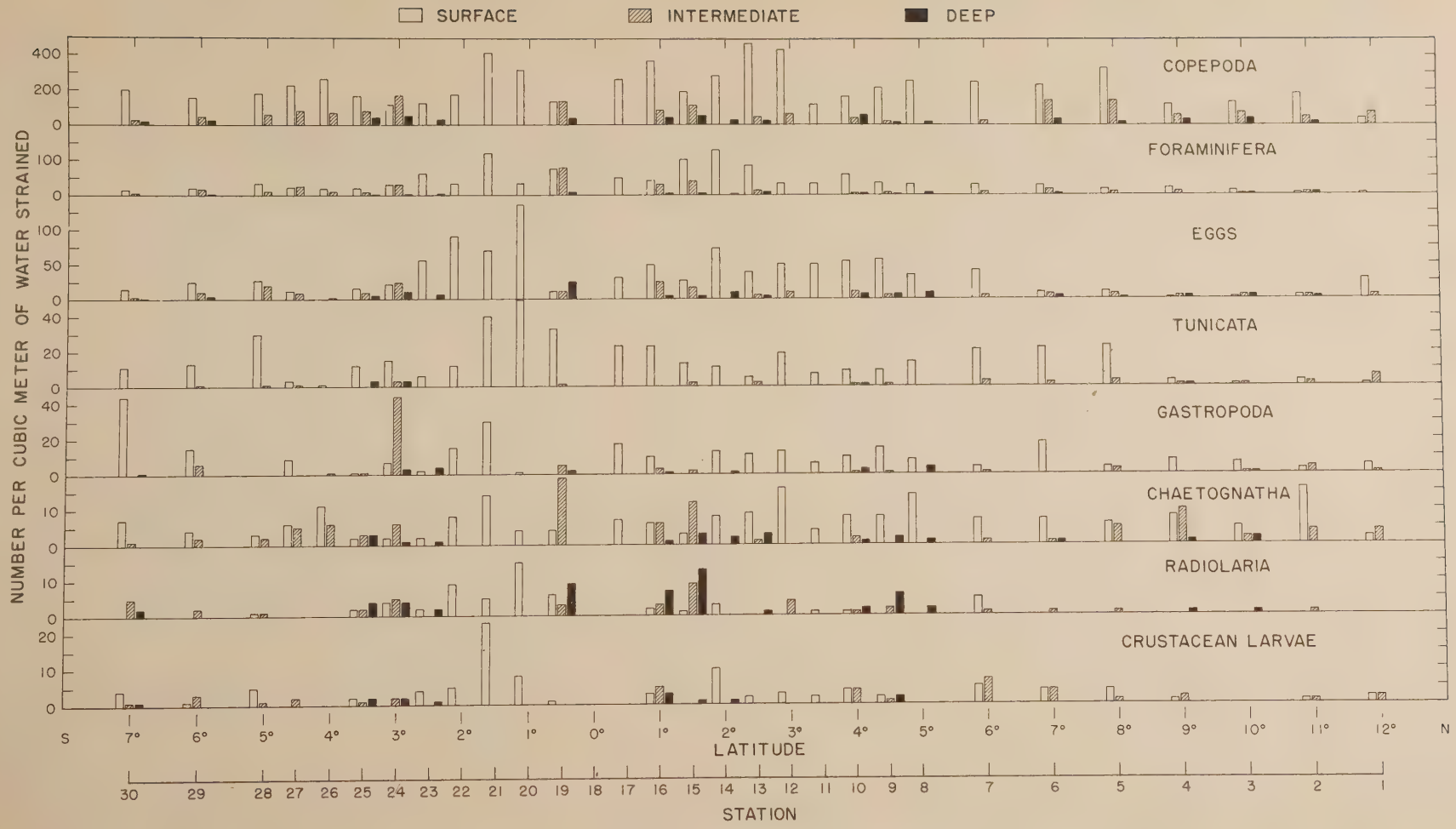
SURFACE
INTERMEDIATE
DEEP
NUMBER PER CUBIC METER OF WATER STRAINED
COPEPODA
FORAMINIFERA
EGGS
TUNICATA
GASTROPODA
CHAETOGNATHA
RADIOLARIA
CRUSTACEAN LARVAE
S 7° 6° 5° 4° 3° 2° 1° 0° 1° 2° 3° 4° 5° 6° 7° 8° 9° 10° 11° 12° N
LATITUDE
30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
STATION

Figure 8. -- Horizontal and vertical distribution of eight major groups of the zooplankton sampled on Hugh M. Smith cruise 16.

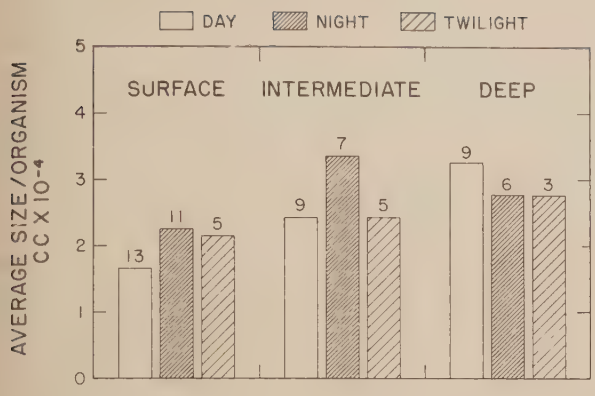

Figure 9.-- Variations in average size of the organisms in the collections of cruise 16 calculated by dividing the displacement volume of the sample by the estimated number of constituents. (Number of samples is indicated above each block.)

A comparison of the zooplankton populations in the North Equatorial and South Equatorial currents was made by a detailed examination of the composition of the zooplankton at two typical night stations, station 3 on latitude 10°N. in the North Equatorial Current and station 13 on latitude 2°30'N. in the South Equatorial Current. The list of organisms (table 4) is not complete for any of the samples but does include the dominant forms as well as certain of the less abundant species. Of the 28 kinds of copepods identified or partially identified from the six collections, only 13 were noted at both stations. The species occurring in greatest abundance at station 3 in the North Equatorial Current were Euchaeta prestandreae and Calanus minor while Pleuromamma abdominalis, Rhincalanus cornutus, and Eucalanus attenuatus were the most abundant species at station 13 in the South Equatorial Current.

There are a few notable similarities in the distribution of species recorded at both stations: e.g., Pleuromamma ziphias and Phronimella elongata were found only in the surface samples at the two stations; Euphausia diomedeae was obtained in the intermediate and surface samples at both stations but not at the deep level. Among the remainder of the organisms there appeared to be no pattern of vertical stratification. According to references in the available literature, all of the 23 identified species of copepods have been collected at the surface or at shallow depths, and most are considered to be cosmopolitan in distribution. It would require much more extensive study to determine whether or not there exist groups of organisms with preponderant tendencies to inhabit certain portions of the equatorial current system or certain levels within these portions.

COMPARISON WITH OTHER SAMPLING METHODS

This series of collections obtained with Clarke-Bumpus samplers, with finer meshed nets and with a smaller (5-inch) mouth opening than the 1-meter nets which have been regularly employed in POFI's plankton surveys, might be expected to sample a somewhat different element of the zooplankton community. Tables 9 and 10 have been compiled to provide a comparison.

Two series of hauls employing 1-meter nets of 30XXX grit gauze and oblique tows to 200 meters depth were made on Hugh M. Smith cruises 5 and 11 and were taken at approximately the same time of year and in about the same area as the Clarke-Bumpus hauls of cruise 16. The average zooplankton volumes of 37.9 and 36.0 cc/1000m^3 obtained on these two sections are considerably less than the average volume (64.7 cc/1000m^3) of the Clarke-Bumpus surface hauls, and greater than the average volumes for the intermediate (29.2 cc/1000m^3) and deep (16.6 cc/1000m^3) levels of hauling (table 9). The standard deviations of these different lots of data vary in about the same manner. When we examine the coefficients of variation, which provide a measure of average variation independent of the mean, we find the largest value (61.3 percent) for the 1-meter net hauls of cruise 5; the coefficient of 47.8 percent for cruise 11 does not differ greatly from 45.1, 39.0, and 41.0 percent, the coefficients obtained for the surface, intermediate, and deep hauls of the Clarke-Bumpus samples. Thus neither the average volume nor the variance differed appreciably between the two types of gear.

The composition of the catches (table 10) obtained by these two methods indicates that the 56XXX mesh retains a much larger number of Copepoda, particularly the microcalanid and cyclopoid copepods of length less than 1 mm., which may be important constituents of tropical

Table 8.--Summary of average numbers and percentage composition of the major groups of zooplankton collected on Hugh M. Smith cruise 16

Organisms	Surface		Intermediate		Deep	
	Average number/m^3	Percentage comp.	Average number/m^3	Percentage comp.	Average number/m^3	Percentage comp.
Copepoda	226.0	65.3	78.0	63.2	33.6	59.0
Foraminifera	40.6	11.7	15.4	12.5	3.2	5.6
Eggs	35.8	10.3	9.3	7.5	6.1	10.7
Tunicata	15.0	4.3	1.5	1.2	0.5	0.9
Gastropoda	9.5	2.7	3.5	2.8	1.1	1.9
Chaetognatha	7.0	2.0	4.4	3.6	1.3	2.3
Radiolaria	2.1	0.6	2.0	1.6	3.0	5.3
Crustacean larvae	3.3	1.0	1.9	1.5	0.7	1.2
Ostracoda	0.2	0.1	3.2	2.6	4.1	7.2
Euphausiacea	3.1	0.9	1.2	1.0	1.5	2.6
Siphonophora	1.6	0.5	0.6	0.5	0.2	0.4
Amphipoda	0.5	0.1	0.4	0.3	0.2	0.4
Miscellaneous	1.3	0.4	2.0	1.6	1.4	2.5

Table 9.--Comparison of average volume of catch and degree of variance in results obtained with Clarke-Bumpus samplers and 1-meter (mouth diameter) nets

	Hugh M. Smith 16			Hugh M. Smith 5	Hugh M. Smith 11
Longitude sampled	150°W.			158°W.	150°W.
Range of latitude	7°S.-12°.N			5°S.-21°N.	5°S.-19°N.
Month and year	July-August 1952			July-August 1950	Sept.-Oct. 1951
Sampling device	Clarke-Bumpus sampler			1-meter nets	1-meter nets
Net material	56XXX grit gauze			30XXX grit gauze	30XXX grit gauze
Mesh aperture width	0.31 mm.			0.65 mm.	0.65 mm.
Type of haul	Horizontal			Oblique	Oblique
Depth of haul	Surface	Interm.	Deep	200 m. to surface	200 m. to surface
Number of observations	29	21	18	24	23
Average sample volume ($\bar{x}$), cc/1000m^3	64.7	29.2	16.6	37.9	36.0
Variance (s^2)	850.7	129.9	46.2	474.3	296.7
Standard deviation(s)	29.2	11.4	6.8	23.2	17.2
Coefficient of variation ($s/\bar{x}$), as percent	45.1	39.0	41.0	61.3	47.8

Table 10.--Comparison of differences in composition of zooplankton catches obtained with Clarke-Bumpus samplers using 56XXX grit gauze nets (Hugh M. Smith cruise 16, horizontal hauls) and those obtained with 1-meter (mouth diameter) 30XXX grit gauze nets (Hugh M. Smith cruise 5, oblique hauls)

	Cruise 16						Cruise 5	
	Surface		Intermediate		Deep		200 m. oblique	
	Average number per m^3	Percent comp.	Average number per m^3	Percent comp.	Average number per m^3	Percent comp.	Average number per m^3	Percent comp.
Copepoda	226.0	65.3	78.0	63.2	33.6	59.0	21.8	53.0
Foraminifera	40.6	11.7	15.4	12.5	3.2	5.6	4.1	9.9
Eggs (mostly invertebrate)	35.8	10.3	9.3	7.5	6.1	10.7	1.7	4.0
Tunicata	15.0	4.3	1.5	1.2	0.5	0.9	2.3	5.6
Chaetognatha	7.0	2.0	4.4	3.6	1.3	2.3	4.1	10.0
Euphausiacea	3.1	0.9	1.2	1.0	1.5	2.6	1.4	3.5
Siphonophora	1.6	0.5	0.6	0.5	0.2	0.4	1.4	3.4
Miscellaneous	16.9	4.9	13.0	10.4	10.5	18.5	6.1	10.6

plankton. The greater retention of Foraminifera, small invertebrate eggs, and Appendicularia (Tunicata) is also evident. The other major groups of the zooplankton are apparently captured in about equal proportions by the two methods.

The tendency for the capture of smaller organisms with the finer meshed, smaller mouthed Clarke-Bumpus gear, noted qualitatively above, can be expressed quantitatively by comparison of average size of organisms taken on cruises 5 and 16, from which both volumes and counts are available (table 11). In most of the hauls of cruise 16, employing the Clarke-Bumpus gear, the average size of organisms was between 1 and 3 x 10^{-4} cc., while in most of the hauls of cruise 5 the average size was between 6 and 14 x 10^{-4} cc. The mean size of organism in the samples (each sample given equal weight) was about five times as large for the coarse-meshed meter net of cruise 5 as for the fine-meshed nets of cruise 16. It is quite obvious that the gear of the two cruises exercised a strong size selection in sampling the plankton community. The volume of catch was not greatly different however, indicating that with the larger net of coarse mesh the loss in small organisms was compensated by the less successful dodging of the larger organisms.

Table 11.--Average size of individuals in zooplankton hauls of cruise 16, employing Clarke-Bumpus samplers equipped with 56XXX grit gauze nets, and in hauls obtained on the eastern leg (158° W. longitude) of cruise 5 employing 1-meter nets of 30XXX grit gauze

Average size at center of class interval, in cc. x 10^{-4}	Number of hauls				
	Cruise 16				Cruise 5
	Surface	Inter-mediate	Deep	Total	
1	7	2	-	9	-
2	18	11	6	35	-
3	2	5	7	14	-
4	2	1	3	6	1
5	-	1	2	3	1
6	-	-	-	-	5
7	-	-	-	-	1
8	-	1	-	1	4
9	-	-	-	-	2
10	-	-	-	-	4
11	-	-	-	-	1
12	-	-	-	-	2
13	-	-	-	-	2
14	-	-	-	-	1
Mean (x 10^{-4} cc)				1.9	9.2

SUMMARY AND CONCLUSIONS

1. At 30 stations in a series along 150°W. longitude from 12°N. to 7°S. latitude, 68 samples were obtained at three depths--the surface, the level of the 70°F. isotherm, and at approximately 200 meters--by means of horizontal closing-net hauls with Clarke-Bumpus samplers.

2. According to an analysis of variance, for surface hauls the volumes of the night samples were significantly greater ($P < 0.01$) than the volumes of the day samples. For intermediate and deep levels the volumes of the day hauls exceeded those of the night hauls, but the differences were not statistically significant.

3. Within the range of latitudes sampled, the area 2°S. to 8°N. contained the greatest amount of zooplankton, with a peak in abundance near 1°S. latitude.

4. The surface samples ranked considerably above the intermediate and deep samples in volume and number of organisms. There was no evidence of a concentration of zooplankton in the region of the thermocline.

5. The average size of organisms in the collections increased with depth of sampling, and was greater in the night hauls than in the day hauls except at the deep level, where the opposite was true.

6. The copepods were by far the most abundant group present in the samples, followed by foraminifers, eggs, tunicates, gastropods, chaetognaths, radiolarians, crustacean larvae, ostracods, euphausiids, siphonophores, and amphipods in that order.

7. A detailed examination of collections obtained at two stations, one in the North Equatorial Current and the other in the South Equatorial Current, provided little evidence of major differences in species composition between these two current sytems.

8. Clarke-Bumpus samplers equipped with 56XXX grit gauze nets retained large numbers of small Copepoda, Foraminifera, and Appendicularia which passed through the coarser meshes of 1-meter nets of 30XXX grit gauze. The volume of catch per unit of water strained was not greatly different, however, for the two types of gear, indicating that with the larger net the loss in small organisms was compensated by the less successful dodging of the larger organisms.

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SIZE FREQUENCIES AND GROWTH OF CENTRAL AND WESTERN PACIFIC BIGEYE TUNA

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The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

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SIZE FREQUENCIES AND GROWTH OF CENTRAL AND WESTERN PACIFIC BIGEYE TUNA

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WASHINGTON: September, 1955

ABSTRACT

Bigeye tuna (Parathunnus sibi) weight data from the Honolulu market for the period 1947-54, length data collected aboard Japanese tuna motherships in the equatorial western Pacific in 1951, and published length frequency distributions from the Japanese longline fishery in the northwest Pacific were compared and studied for evidence of growth and of local differences in the size composition of the population. In the data from both the equatorial western Pacific and Hawaiian waters the modes of the male size distributions were found to be about 14 cm. or 30 pounds larger than the corresponding female modes. Monthly weight frequencies of Hawaiian bigeye showed a consistent progression of modes, yielding a provisional growth curve that indicates that these fish may gain as much as 50 pounds in 1 year and may live about 6 or 7 years. Relatedness of the bigeye in Hawaiian waters and in the Japanese North Pacific fishery is suggested by the approximately similar growth rates and by the presence of a complementary 2-year cycle of dominant size groups in the catches of both areas. Data from equatorial waters showed no progression of the modes with time.

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The purpose of this analysis of bigeye tuna, Parathunnus sibi (Temminck and Schlegel) = P. mebachi (Kishinouye)[1/], measurements is to learn about growth and migration of this species from the size composition of commercial longline catches. Consideration of size frequencies from the Hawaiian and the Japanese North Pacific fisheries yields evidence of a relationship which suggests that there is but a single stock of bigeye being exploited by both fisheries. These data also furnish evidence of rapid growth of bigeye tuna. Other facets of the biology of the species, such as size differences associated with sex, are revealed by Japanese catches in the equatorial Pacific and Hawaiian catches. Measurements obtained on Japanese mothership expeditions in the western equatorial Pacific, which will be discussed, supply information on size differences associated with sex and evidence pointing to a migration of this species. (The size frequencies on which this study is based are presented in tabular form in the appendix.)

The bigeye tuna is of considerable importance in the Hawaiian longline (flagline) fishery, where catches are sold on the Honolulu fresh fish market. The operation of the Hawaiian fishery has been described and catch statistics analyzed by June (1950) and Otsu (1954). In 1952, a year of high abundance, the value of the landings to the fishermen is given by Otsu as $684,726. The same author also describes the seasonal trend in apparent abundance, pointing out that the lighter catches occur from June to September and the heavier catches from October to May. The catch of this species increased sharply from 126,000 pounds

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[1/] Parathunnus sibi (Temminck and Schlegel) is regarded as a synonym of P. mebachi (Kishinouye) by numerous authors, among them Brock (1949) and Nakamura (1949). For the purpose of this paper they will be considered a single species.

in 1946 to 2,193,000 pounds in 1952. The years 1953 and 1954 similarly show high catches of 2,826,000 pounds and 2,759,000 pounds respectively.[2/]

The bigeye tuna is also important in the Japanese high seas longline fishery, which covers vast areas of the western and central Pacific Ocean, extending as far east as Hawaii. Following World War II, Japanese mothership expeditions, described by Shimada (1951a and b), Ego and Otsu (1952), Van Campen (1952), and Murphy and Otsu (1954), landed considerable numbers of bigeye tuna. These expeditions operated from about 1° to 10°N. latitude and 134° to 179°E. longitude. Farther to the north there is a Japanese longline fishery for deep-swimming tunas, including bigeye, which has been described by Shapiro (1950). The area covered by this North Pacific fishery is usually north of 26°N. latitude and between 130°E. and 165°W. longitude.

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Appreciation is extended to the individuals, too numerous to mention, who have aided in the collection of measurements and offered direction in preparing this report. To the Hawaii Fishing Co., Ltd., and the United Fishing Agency indebtedness is acknowledged for permission to examine sales records. To Mr. T. Nakata thanks are extended for the preparation of figures in this report.

MATERIAL AND METHODS

For most of the Hawaiian specimens only the weight (obtained from market sales slips) is available. Length measurements taken on the Japanese mothership expeditions were in millimeters from the tip of the snout with jaws closed to the median portion of the caudal fork (with fleshy flap depressed) as described by Marr and Schaefer (1949). Additional length frequencies were obtained from Japanese reports. Prior to analysis length measurements were tabulated in 2-centimeter intervals, and weight measurements in 10-pound intervals. When it was necessary to convert from length to weight, the relationship log weight (pounds) = -7.1167 + 2.9304 log total length (millimeters), based on Hawaiian samples, was used. To smooth data, a moving average of three was applied.

[2/] From unpublished records of the Division of Fish and Game, Board of Commissioners of Agriculture and Forestry, Territory of Hawaii.

Since the successful interpretation of growth from time series of size frequency distributions depends on an objective and realistic method of locating modes, the following criteria were adopted:

1. No modes have been sought in distributions containing less than 100 fish.

2. Each mode must be separated from every other mode by troughs dipping at least 5 fish below modes after smoothing.

3. Each mode must be present in the data for at least two not too widely separated months.

4. At least two of the groups making up the mode must have no less than 15 individuals each before smoothing, or at least 10 individuals if the modal peak is present in two adjacent months.

5. The mode must be the center group of a peak of the smoothed distribution or the center group of two or more minor peaks which differ by less than 5 fish in height.

SIZE DIFFERENCE BY AREAS

Bigeye tuna taken on commercial longline gear are smaller in the western than in the central Pacific (Kamimura and Honma 1953, Murphy and Shomura 1953b, and Murphy and Otsu 1954). In their report, Murphy and Shomura state that longline fishing west of 180° longitude yielded bigeye that averaged about 40 pounds lighter in weight than those taken between 180° and 120°W. longitude. This interesting phenomenon is believed by them to be related to ecological conditions, however, Iversen[3/] points out that this type of size segregation can be the result of migration.

SEXUAL DIFFERENCE IN CATCH

The bigeye males achieve a larger average size than the females, for all recognizable male modes are to the right of the corresponding female modes. Size distributions from the Hawaiian Islands (fig. 1) and the western Pacific (137° - 165°E. longitude) (fig. 2) show a parallel size differential between the sexes.

[3/] MS. Size variation of central and western Pacific yellowfin with age and area.

In view of this size difference it is of interest to examine the sex ratio for possible variation throughout the year. Aside from intrinsic interest, this is advisable because a periodic change in the sex ratio could shift the positions of the modes of unsexed samples and make an analysis of growth misleading. The mean percentage of males for Hawaiian bigeye for the year 1949 was 59.2 percent and for 1951, 57.5 percent (Otsu 1954). The larger samples (over 100 specimens) from these same years and December of 1950, when tabulated by months (table 1), indicate that the sex ratio remained rather constant at about 60 percent males throughout the year.

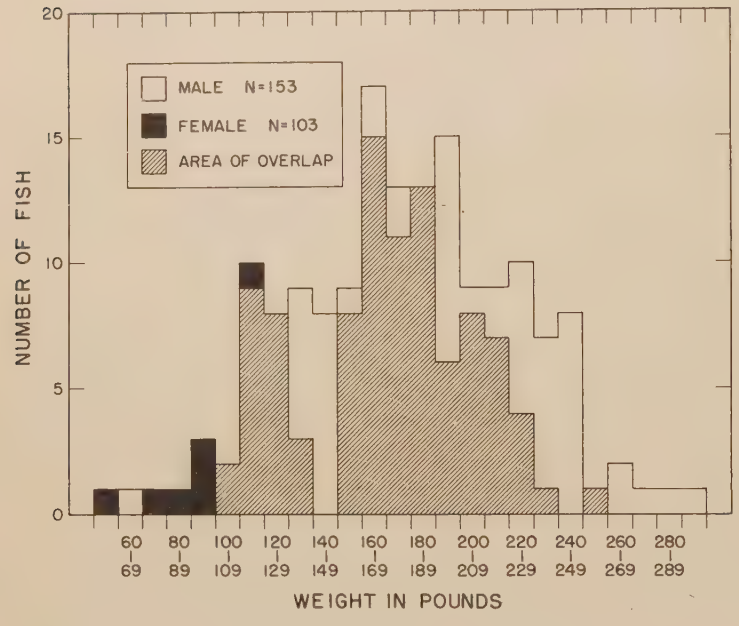


Figure 1.--Weight frequency distributions of bigeye tuna landed at the Honolulu market from May to August 1951.

The possibility that the sex ratio changes as the fish grow requires examination because this could affect the position of modes based on unsexed samples. Otsu (1954) states "....the sex ratio in the catch /fifth Japanese mothership expedition/ below 80-90 pounds is about equal, whereas the males predominate among the larger bigeye and yellowfin." However, if the female bigeye size frequency distribution is shifted a distance equal to the average growth lag between sexes, the apparent change in sex ratio with increase in fish size disappears.

Figure 3, lower panel, shows the sex ratios plotted by size groups from the data used by Otsu (fig. 2). The proportion of males increases with an increase in the size of the fish. (The small numbers in the extreme groups connected with dashed lines are better ignored.)

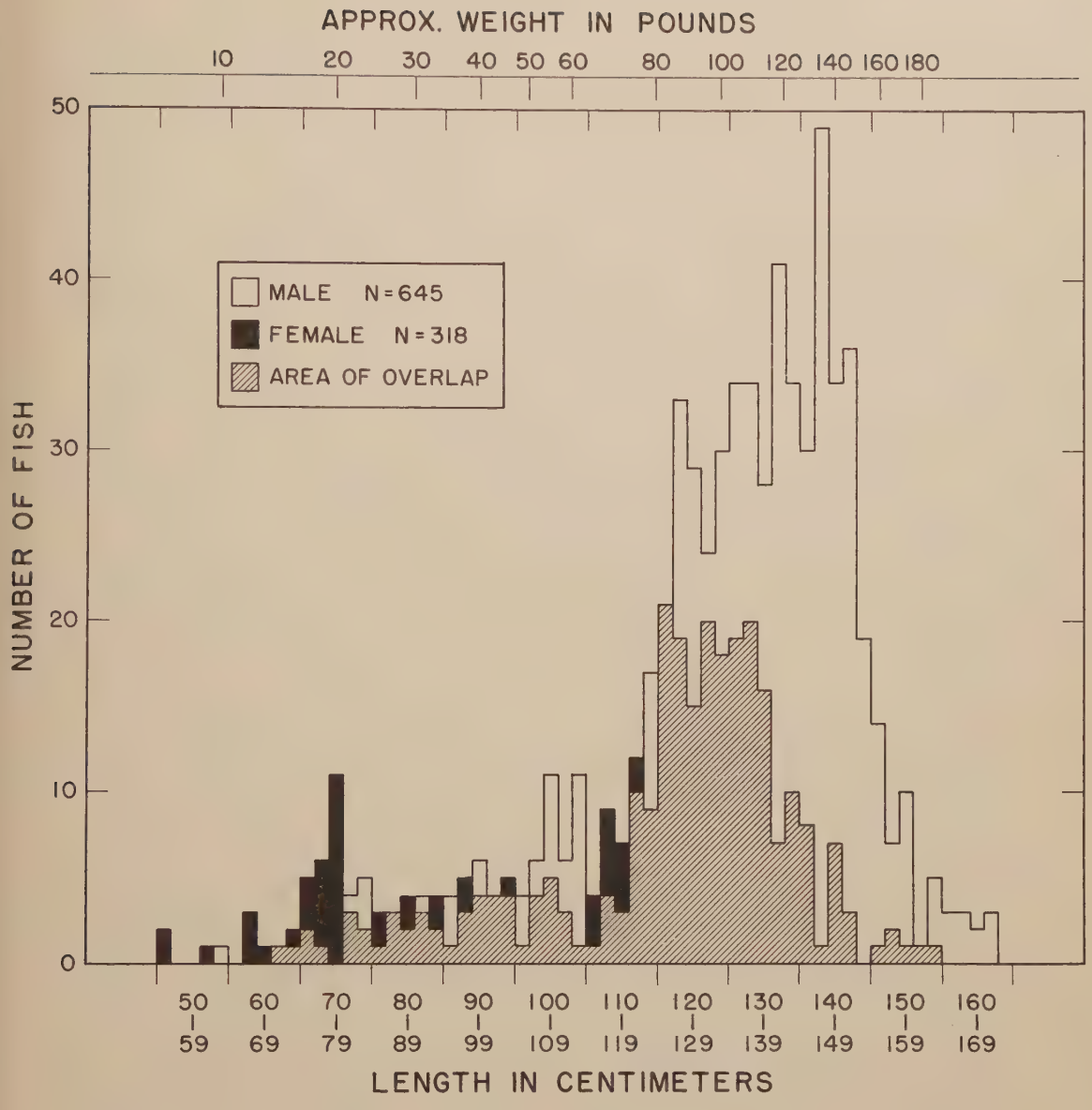


Figure 2.--Length frequency distributions of bigeye tuna from 137°- 165°E. longitude taken between March 29 and May 28, 1951.

In the upper panel the female size groups have been moved 14 cm. to the right (approximate average difference in size related to sex), and the resultant trend indicates that the sex ratio is constant at about 60 percent males throughout the size range studied.

Table 1.--Monthly sex ratio of Hawaiian bigeye tuna

Months	Males	Females	Total	Percent Males
1949				
Jan.-Feb.	32	18	50	64.0
Mar.	16	16	32	50.0
Apr.	5	10	15	33.3
May	7	3	10	70.0
June-Aug.	10	1	11	90.9
Sept.	30	11	41	73.2
Oct.	41	35	76	53.9
Nov.	100	65	165	60.6
Dec.	105	79	184	57.1
Total	346	238	584	59.2
1950				
Nov.	5	9	14	35.7
Dec.	102	59	161	63.4
1951				
Jan.	38	24	62	61.3
Feb.	24	25	49	49.0
Mar.	42	57	99	42.4
Apr.	65	39	104	62.5
May	82	43	125	65.6
June	51	34	85	60.0
July	57	50	107	53.3
Aug.	35	25	60	58.3
Sept.	40	43	83	48.2
Oct.	89	70	159	56.0
Total	630	478	1108	56.9

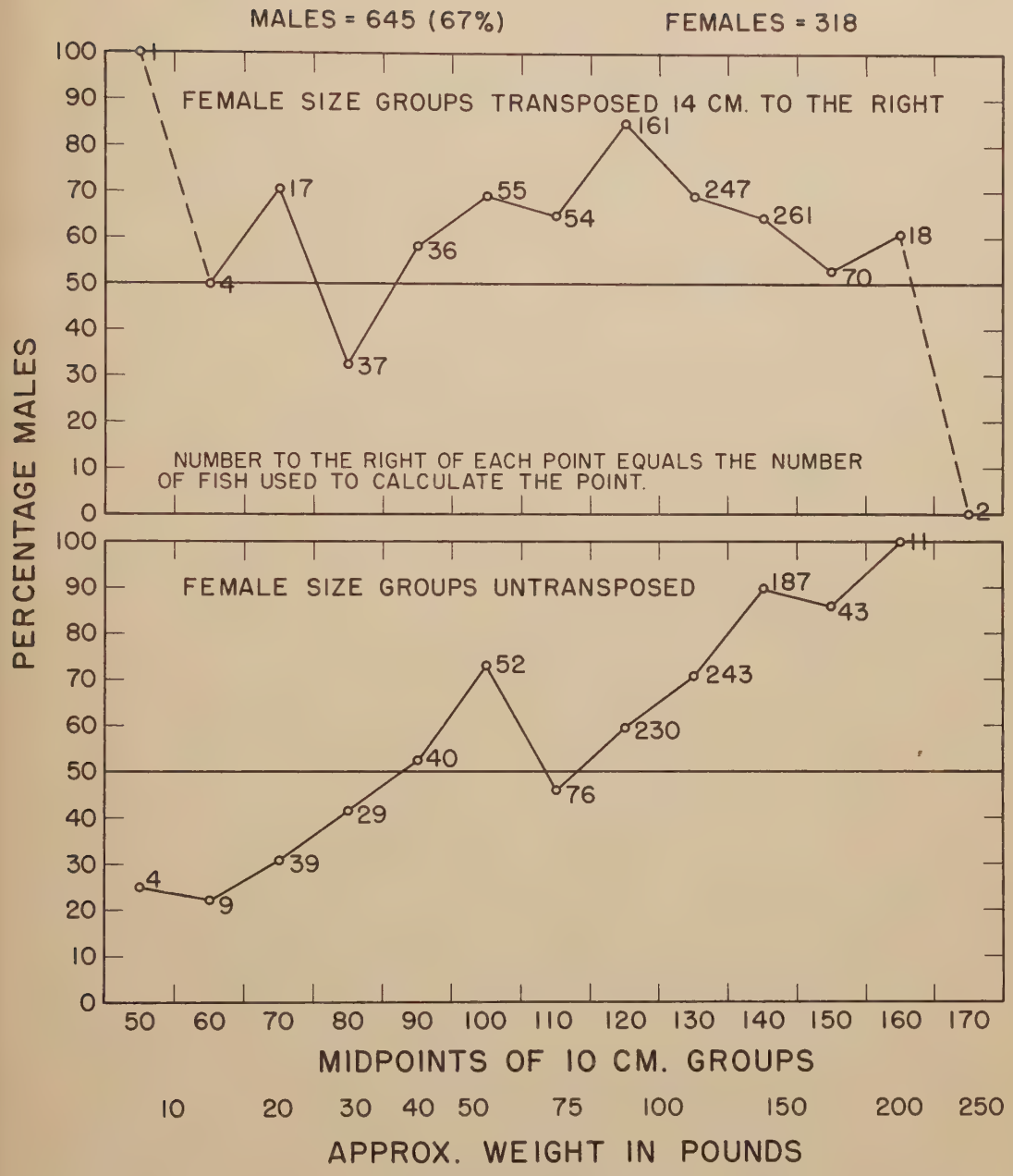

MALES = 645 (67%)
FEMALES = 318
FEMALE SIZE GROUPS TRANSPOSED 14 CM. TO THE RIGHT
NUMBER TO THE RIGHT OF EACH POINT EQUALS THE NUMBER OF FISH USED TO CALCULATE THE POINT.
FEMALE SIZE GROUPS UNTRANSPOSED
PERCENTAGE MALES
MIDPOINTS OF 10 CM. GROUPS
APPROX. WEIGHT IN POUNDS

Figure 3.--Percentage bigeye tuna males in sample by size groups. Sample from 137°-165°E. longitude taken between March 29 and May 28, 1951. Lower panel shows the sex ratios of each size class of the sample in figure 2 (same data used by Otsu (1954)).

INTERYEAR SIZE DIFFERENCES

Before examining size distributions for evidence of growth, it is important to look for groups of similar sizes that appear each year. If detected in the same position year after year these dominant groups can be looked upon as the progeny of annual spawnings (year classes). To make this interyear comparison, monthly Honolulu market weights from November 1947 through December 1954 were plotted as weight frequency graphs (figs. 4-11).

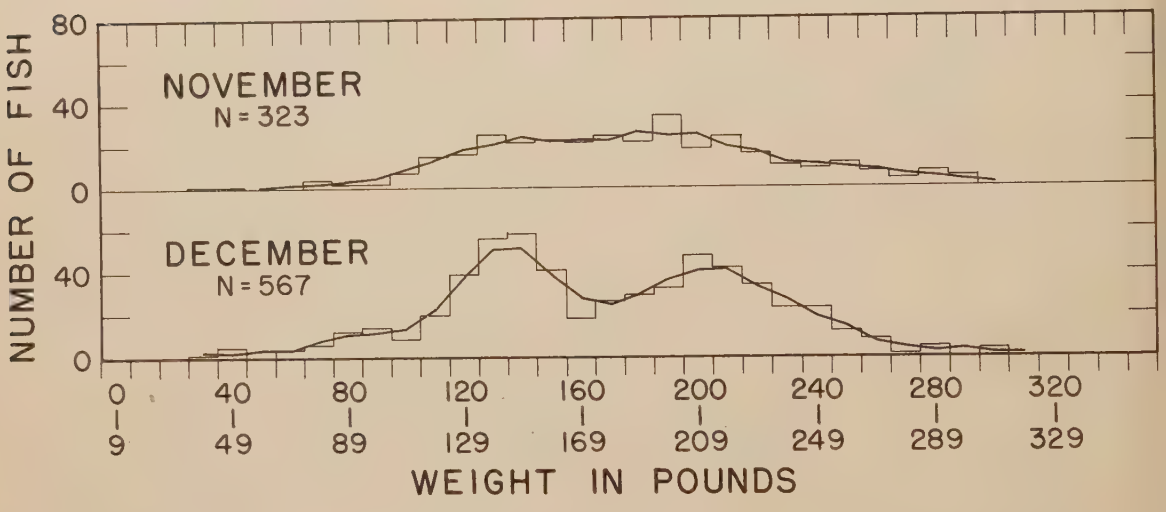


Figure 4.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1947.

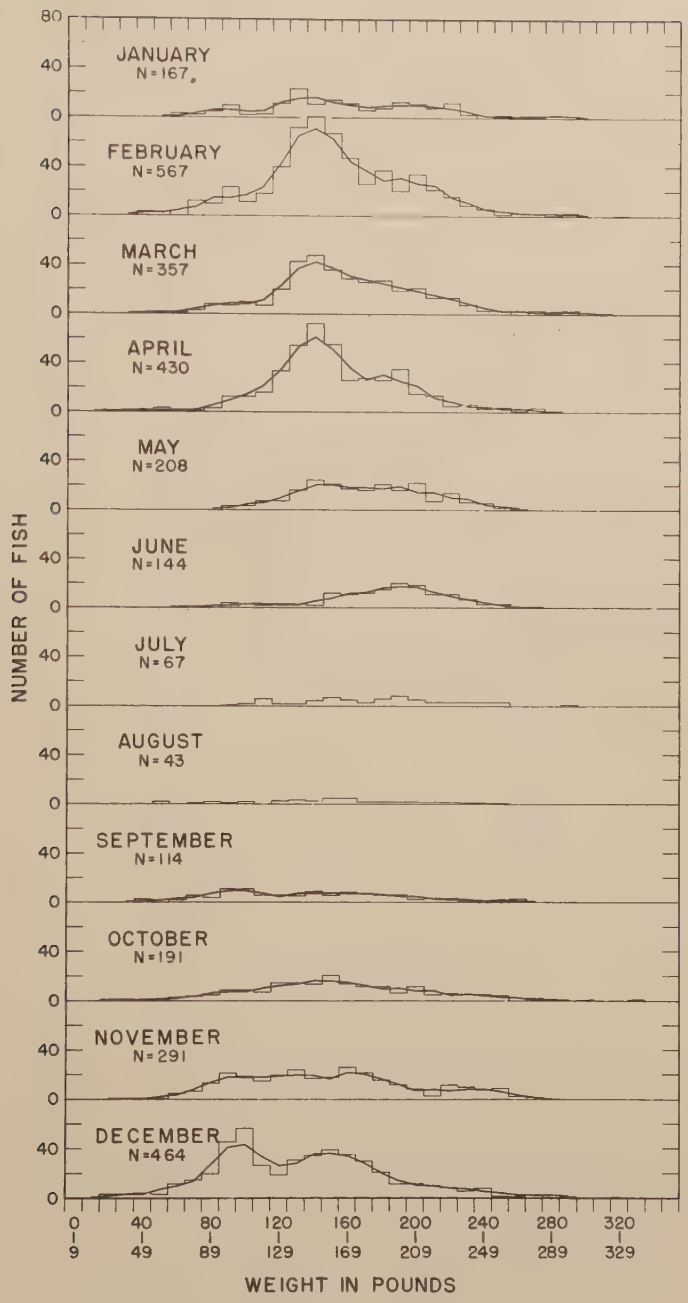


Figure 5.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1948.

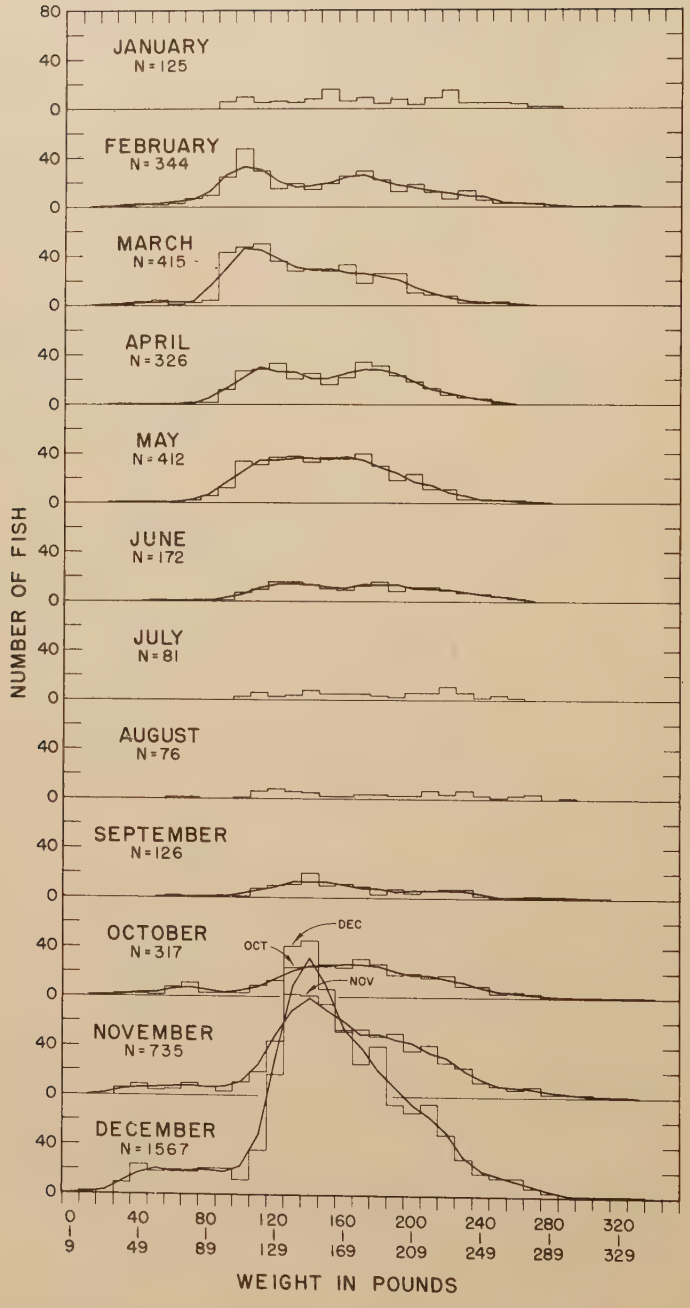
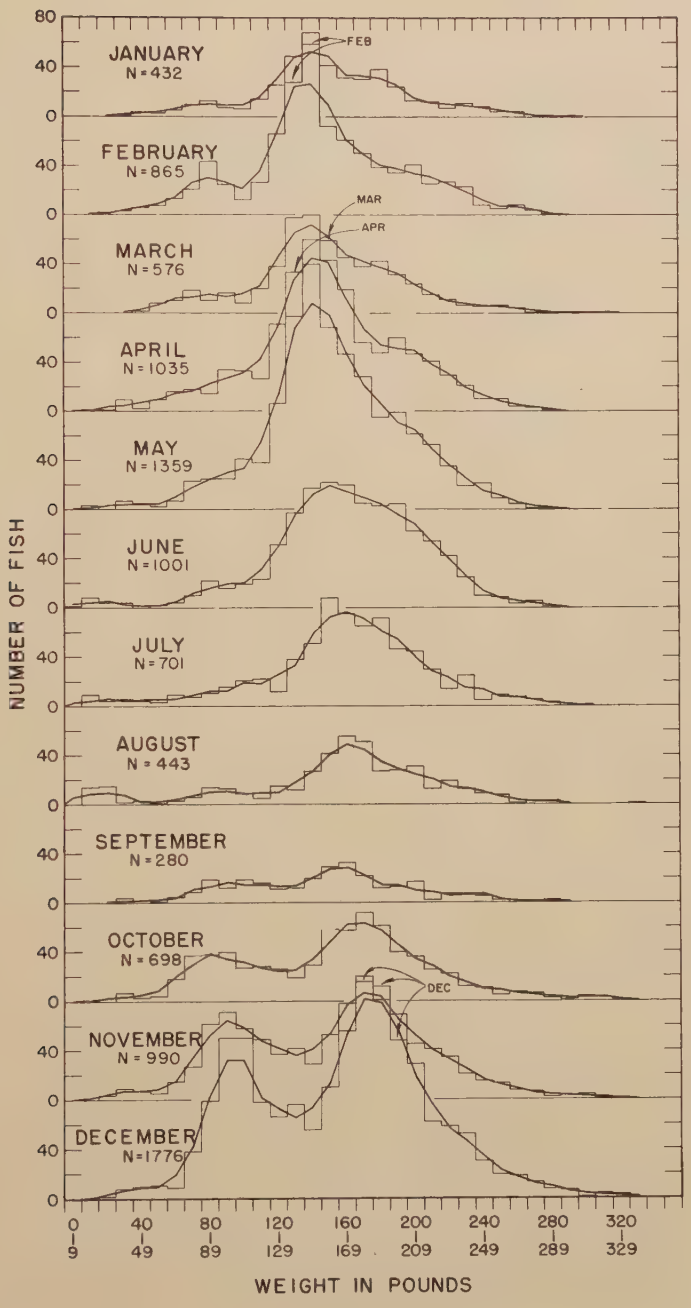


Figure 6.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1949.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AUGUST
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OCTOBER
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DEC
NOVEMBER
N=990
DECEMBER
N=1776
NUMBER OF FISH
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80
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40
0
40
0
40

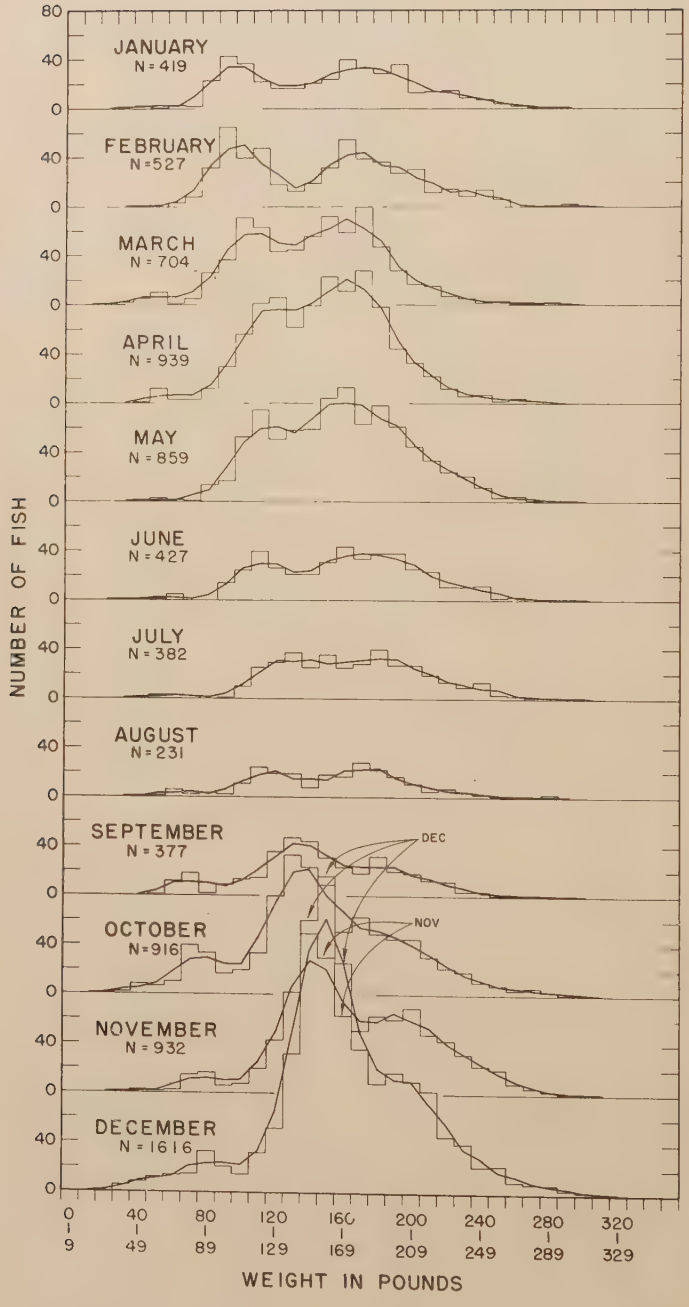


Figure 8.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1951.

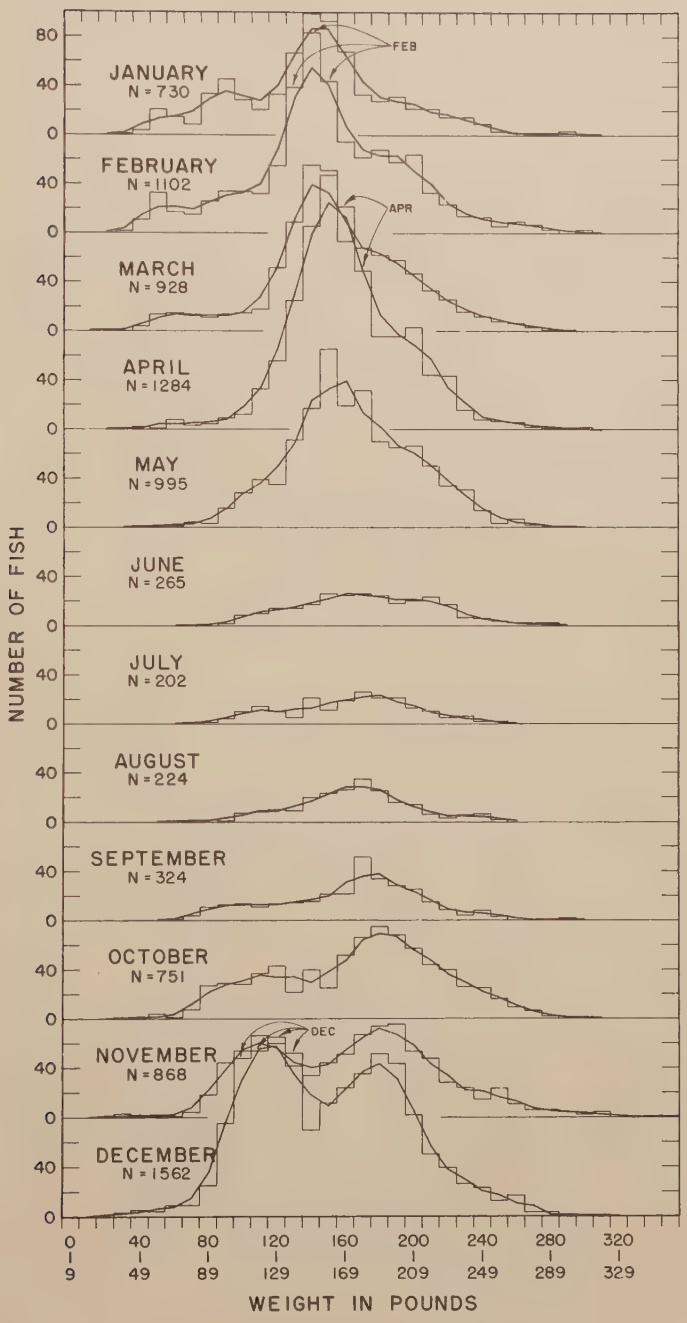


Figure 9.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1952.

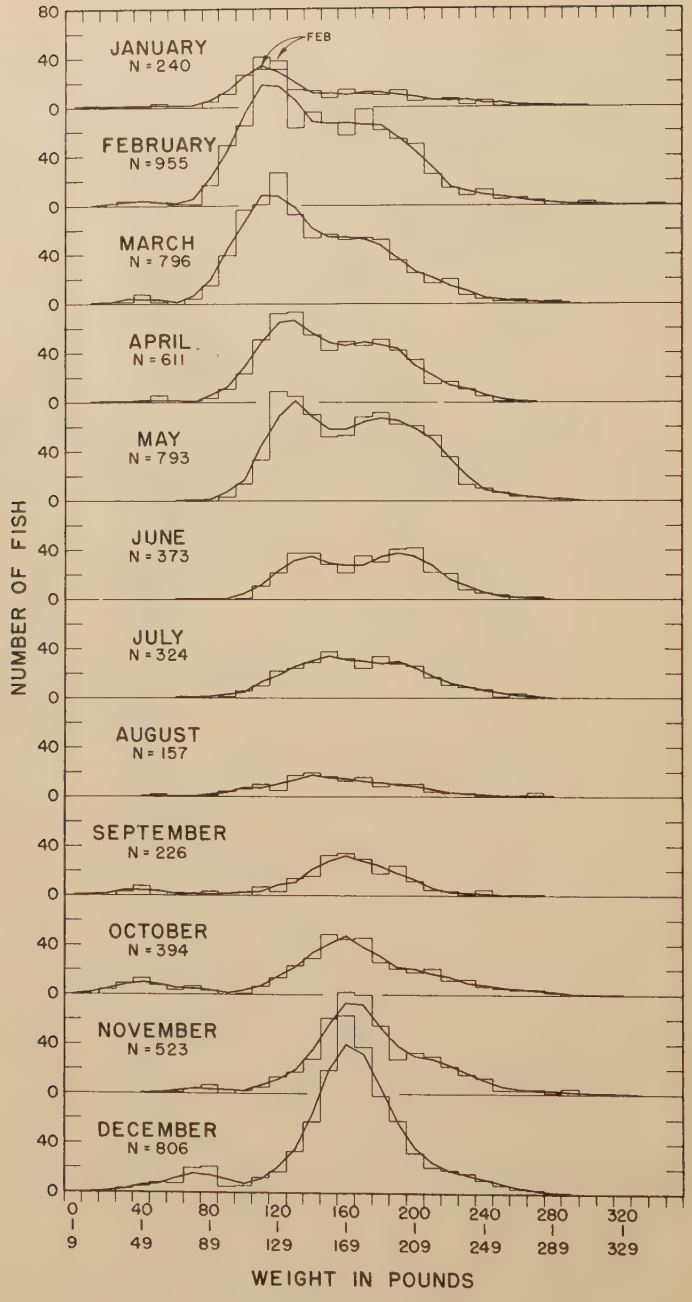
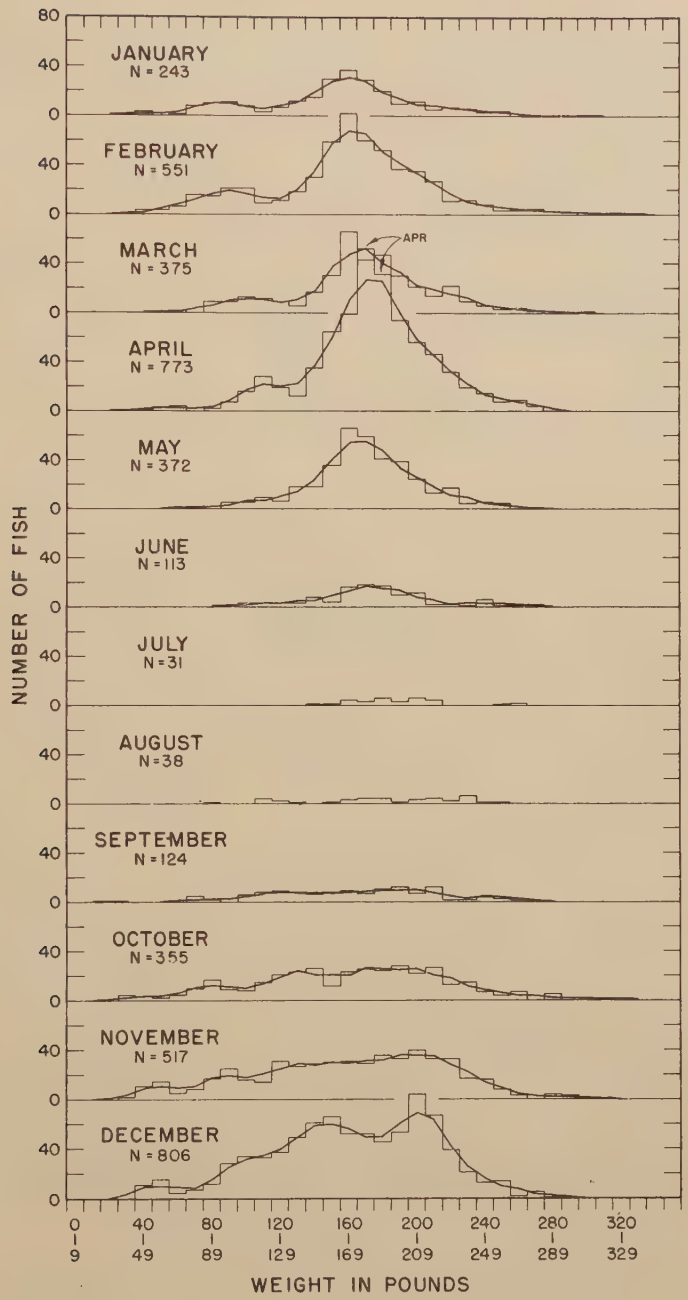


Figure 10.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1953.


JANUARY
N = 243
FEBRUARY
N = 551
MARCH
N = 375
APR
APRIL
N = 773
MAY
N = 372
JUNE
N = 113
JULY
N = 31
AUGUST
N = 38
SEPTEMBER
N = 124
OCTOBER
N = 355
NOVEMBER
N = 517
DECEMBER
N = 806
NUMBER OF FISH
0
40
80
0
40
0
40
0
40

An interesting aspect of these graphs is the noticeable difference in the positions of the dominant modes between adjacent years. For example, the year 1952 (fig. 9) has a dominant mode at about 150 pounds in January that progresses to 185 pounds by December and a secondary mode beginning at about 95 pounds in January that moves to about 120 pounds in December. The year 1953 (fig. 10), on the other hand, has but a single dominant mode, which is apparent for nearly all months of the year. This can be seen at about 115 pounds in January and progresses to about 165 pounds in December. In comparing the same month there is no evidence of similarly situated dominant modes in the 1952 and 1953 data. This lack of agreement between the dominant modal size groups of adjacent years holds true for all years examined.

There are, however, strong resemblances between the distributions of sizes in alternate years. To illustrate the differences between adjacent years and the resemblances of alternate years, December samples of all available years (1947-1954) have been plotted as percentage weight frequencies in figure 12. It is self-evident that there is a persistent difference between but a similarity within the series of odd- and even-numbered years. This points to a cycle of dominant weight groups with a period of about 2 years.

Dominant modes are not found in exactly the same position each second year, but increase in size (fig. 12). Looking at odd-numbered years first, in December 1947 the dominant mode was centered at 140 pounds, but by December 1953 it had progressed to 165 pounds. For the even-numbered years there are two dominant modal groups that act similarly. A small dominant mode at 105 pounds in the December 1948 sample can be traced through each even-numbered year until it reaches 150 pounds in December 1954. A larger dominant mode that occurred at 155 pounds in 1948 can be seen progressing through all the December samples of even-numbered years, reaching 205 pounds in the 1954 sample.

An average of less than 24 months elapses between the appearance of dominant size groups in the Hawaiian fishery. This is indicated by the "growth lines" fitted by eye (fig. 13) to the modes from the monthly distribution (figs. 5-11, table 2), and by the increasing size of apparently homologous modes as they reappear in the fishery every 2 years (fig. 12). If these modes represent year classes, this could mean that the peak of spawning or spawning survival takes place a little later every second year, which seems unlikely. It is more to be expected that spawning recurs at about the same time each year and

that the increase in the size of the dominant modes (of both the even- and odd-numbered years) from 1947 to 1954 is related to some other change in the population.

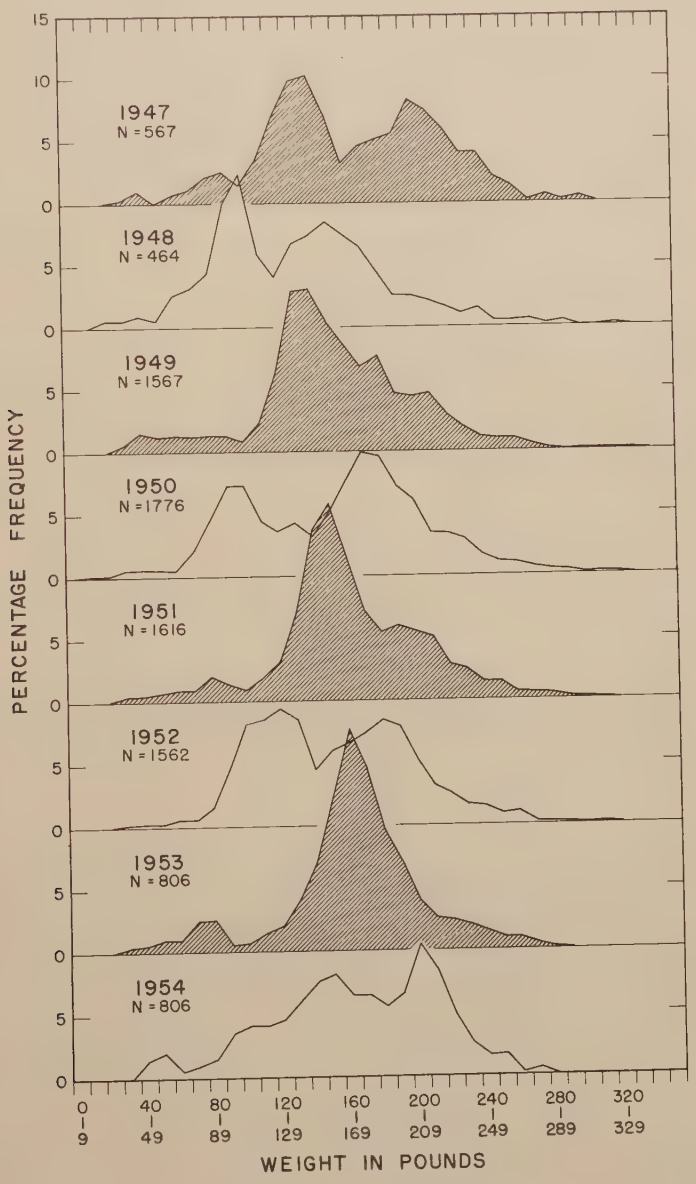


Figure 12.--Hawaiian bigeye tuna weight frequency distributions (percentage) for December samples, 1947 to 1954.

The alternate-year occurrence of certain size groups also takes place in the western Pacific (fig. 14) and it is enlightening to compare the modes of bigeye tuna from the two regions. Kamimura and Honma (1953) and Nakamura et al. (1953) report a "biennial" occurrence of dominant size groups taken in the Japanese North Pacific bigeye fishery. (The sizes of their fish are given in centimeters and were converted to pounds by the Hawaiian length-weight formula.) Nakamura et al. report the modes for November 1948 to March 1949 (1948 season) and for October 1949 to April 1950 (1949 season) (see table 3). Kamimura and Honma list the ranges for all modal groups through the 1952 season and have included the data of Nakamura et al.

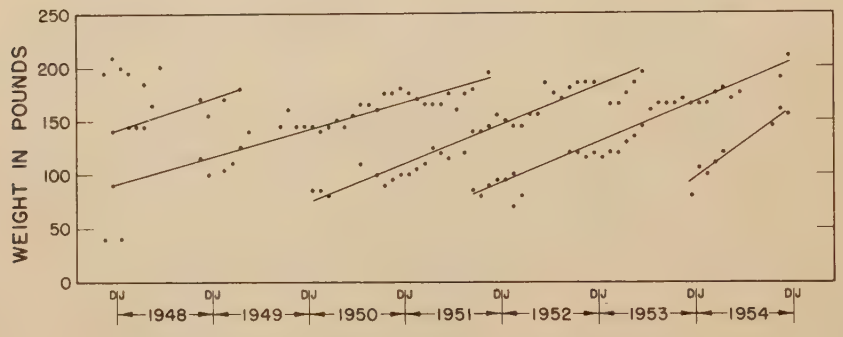


Figure 13.--"Growth lines" of Hawaiian bigeye tuna as determined by modal values, based on the locations of modes in figures 5-11.

Where the Japanese investigators have not indicated modes, they have been selected from their data. Thus modes are available for each of five fishing seasons (1948-1952) (table 3). These modes, plotted as fishing season midpoints on figure 15, together with the growth lines from the Hawaiian fishery (fig. 13), show that modes in the Japanese fishery alternate with those of the Hawaiian fishery within a year, and that the slopes of the "growth lines" for both areas are very similar.[4/] The similarities in the slopes of the growth lines and the presence of complementary cycles of approximately 2 years suggest that the same bigeye population contributes to both fisheries.

[4/] The modes in the Japanese landings have been connected by the present author.

Table 2.--Time and position of observed modal mid-points of Hawaiian bigeye weight frequency distribution (from figures 5-11)

Month and year	Weight (pounds)			Month and year	Weight (pounds)		
1947				1950 (cont'd.)			
November	40	195	-	December	100	180	-
December	90	140	210	1951			
1948				January	100	175	-
January	40	200	-	February	105	170	-
February	145	195	-	March	110	165	-
March	145	-	-	April	125	165	-
April	145	185	-	May	120	165	-
May	165	-	-	June	115	175	-
June	200	-	-	July	160	-	-
July	-	-	-	August	120	175	-
August	-	-	-	September	85	140	180
September	-	-	-	October	80	140	-
October	-	-	-	November	90	145	195
November	115	170	-	December	95	155	-
December	100	155	-	1952			
1949				January	95	150	-
January	-	-	-	February	70	100	145
February	105	170	-	March	80	145	-
March	110	-	-	April	155	-	-
April	125	180	-	May	155	-	-
May	140	-	-	June	185	-	-
June	-	-	-	July	175	-	-
July	-	-	-	August	170	-	-
August	-	-	-	September	120	180	-
September	145	-	-	October	120	185	-
October	160	-	-	November	115	185	-
November	145	-	-	December	120	185	-
December	145	-	-	1953			
1950				January	115	-	-
January	85	145	-	February	120	165	-
February	85	140	-	March	120	165	-
March	80	145	-	April	130	175	-
April	150	-	-	May	135	185	-
May	145	-	-	June	145	195	-
June	155	-	-	July	160	-	-
July	110	165	-	August	165	-	-
August	165	-	-	September	165	-	-
September	100	160	-	October	165	-	-
October	90	175	-	November	170	-	-
November	95	175	-	December	80	165	-

Table 2.--Time and position of observed modal mid-points of Hawaiian bigeye weight frequency distribution (from figs. 5-11)(cont'd)

Month and year	Weight (pounds)			Month and year	Weight (pounds)		
1954							
January	105	165	-	July	-	-	-
February	100	165	-	August	-	-	-
March	110	175	-	September	-	-	-
April	120	180	-	October	145	-	-
May	170	-	-	November	160	190	-
June	175	-	-	December	155	210	-

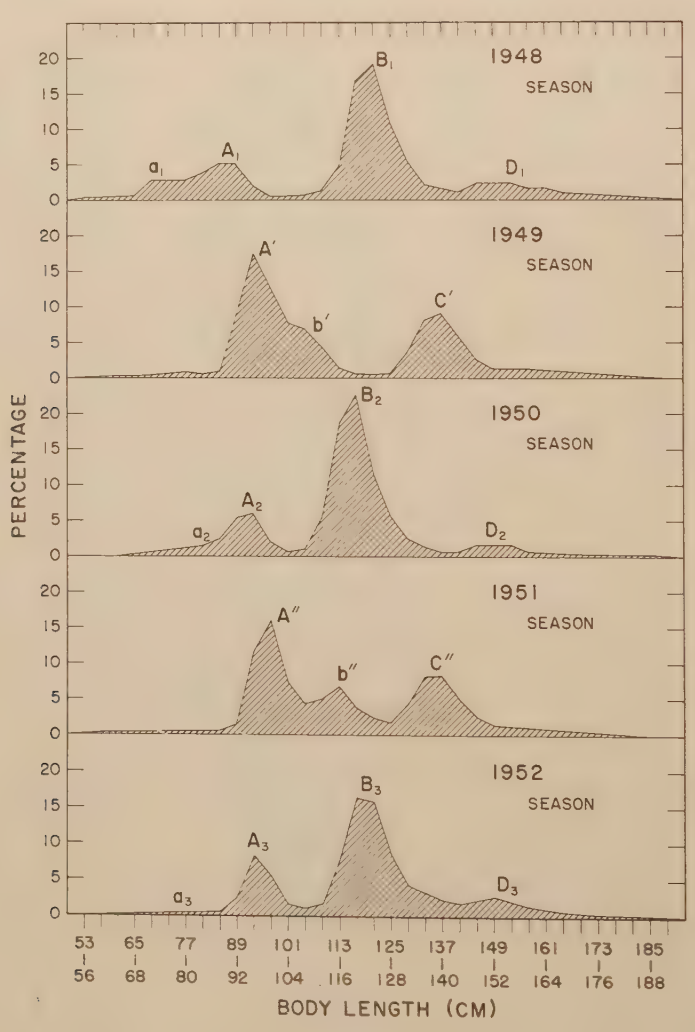


Figure 14.--Bigeye length frequencies by seasons (October-March) for the years 1948-1952. Samples drawn from landings of Japanese commercial vessels operating north of 26°N. between 130°E. and 165°W. longitude. (From Kamimura and Honma (1953))

Table 3.--Modal mid-points and modal ranges from Japanese North Pacific bigeye size frequency distributions

Fishing season	Modal ranges		Modal mid-points	
	From Kamimura and Honma (1953)	Equivalent weight*	From Nakamura et al. (1953)	Equivalent weight*
	centimeters	pounds	centimeters	pounds
1948 season	69-80	16-25	73-76[1/]	19-21
December 1948-	81-96	25-42	85-88	29.4-32.5
March 1949	113-132	68-107	121-124	82.6-88.8
	145-164	140-201	149-152	152-161
1949 season	89-100	34-47	93-96	38.2-41.9
October 1949-	101-116	49-73	105-108[1/]	54.5-59.1
March 1950	132-148	107-149	137-140	119-127
			Located by Iversen	
1950 season	85-100	29-47	92-93	37-38.2
October 1950-	109-128	61-97	117-120	79.4-80.6
March 1951	141-164	129-201	152-153	161-164
1951 season	89-104	34-53	97-100	43.2-47.3
October 1951-	105-124	54-89	113-116	67.7-73.0
March 1952	129-152	100-161	136-137	116-119
1952 season	89-104	34-53	93-96	38.2-41.9
October 1952-	113-136	68-116	120-121	80.6-82.6
March 1953	141-160	129-187	149-152	152-161

* All equivalent weights are estimated from the formula

Log weight (pounds) = -7.1167 + 2.9304 log total length (millimeters)

[1/] Obscure

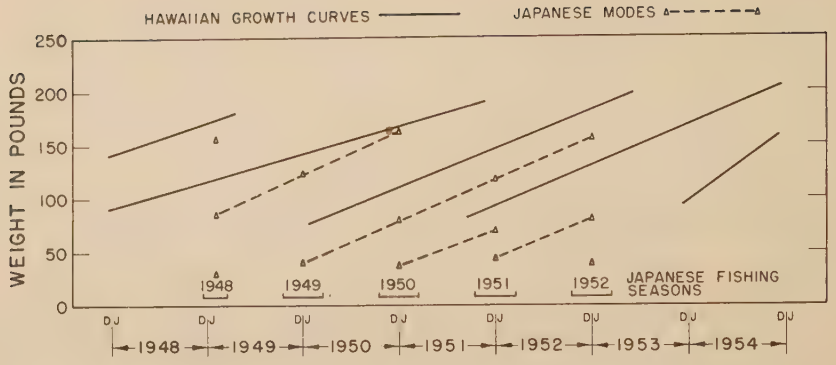


Figure 15.--Comparison of Hawaiian and Japanese bigeye tuna "growth lines" using data from the Japanese North Pacific fishery taken from Kamimura and Honma (1953) and Nakamura et al. (1953).

Nakamura et al. (1953) propose and Kamimura and Honma (1953) discuss at length three hypotheses to explain the "biennial frequency" which they observe in the Japanese North Pacific fishery. These hypotheses are:

"i. Difference in annual propagation;
ii. Difference in annual growth rate;
iii. Difference in annual course of migration."

Kamimura and Honma are unable to decide which hypothesis best fits this phenomenon. They feel that perhaps that of differences in annual propagation (i) is the most reliable and that an annual migratory pattern (iii) may be accepted as a reasonable hypothesis "provided that the fish should take the same migratory route every two years."

Unfortunately even with the added knowledge that this cycle occurs in the Hawaiian fishery there is still insufficient information on the biology of the species to permit a definitive explanation. Some sort of a migratory pattern would seem to best satisfy the relationship of the sizes of bigeye in the two areas. There is considerable circumstantial evidence to indicate that this species may be moving about over a vast expanse of the Pacific. Spawning apparently takes place only over a large area near the Equator, from about 150°E. to 140°W. longitude, and mature or nearly mature females are found there at all times of the year (Kikawa 1953, Yuen 1955). Neither of these authors could find evidence of a spawning area farther to the north. If the

equatorial region is the only area of spawning, those groups of fish from Hawaii and the Japanese North Pacific fishery would have to make an extensive migration to reach this area. Evidence from commercial fishing operations in the western Pacific indicates that there is migration in a north-south direction (Nakamura 1949, Honma and Kamimura 1955).

Further evidence for extensive migration of Pacific bigeye can be seen in modes resulting from measurements of fish at the Equator. Murphy and Otsu (1954) give length frequencies for bigeye measured during the Japanese mothership expeditions west of 180° longitude. These have been plotted using their 5-cm. groups in figure 16. The distributions, which cover June 1950 through October 1951, show that throughout the year a mode is present at about 130-135 cm. (102-114 pounds) that does not appear to progress. During September and October of 1951 a lesser mode appears at about 92-97 cm. (37-43 pounds) that is not present in the other samples. The lack of modal progression with time indicates a constant movement of bigeye into and out of the depths sampled by the longline gear or into and out of the geographic area fished. The occurrence of modes during September and October of 1951 that are not present in the other distributions is also an indication of the migration of a size group into the sampling area.

Additional evidence of migration is found in the Japanese North Pacific fishery, where there is an increase in abundance of the larger size groups with an accompanying decrease in the smaller size groups as one goes from west to east (Nakamura et al. 1953). Since it seems safe to assume that the species grows, the difference in size with area indicates that there are regular and perhaps complex migrations. In figure 15 it can be seen that the Japanese catches have smaller modes (30-40 pounds) than can be found in the Hawaiian catches (the smallest in the Hawaiian data are usually about 80-90 pounds). However, it is also interesting to note that these very small modes appear to be present each year rather than biennially, and that the large modes that occur at about 180-200 pounds in the Hawaiian fishery are not seen in the Japanese fishery.

By way of review, the modal groups of bigeye tuna in the several areas (fisheries) present several puzzling problems. Near the Equator, where ripe fish are taken, there is no progression of modes. In the more northern areas, where spawning has not been noted, the modes progress with time, but there is a curious alternation of modes between years when considering a single area. Considering two well

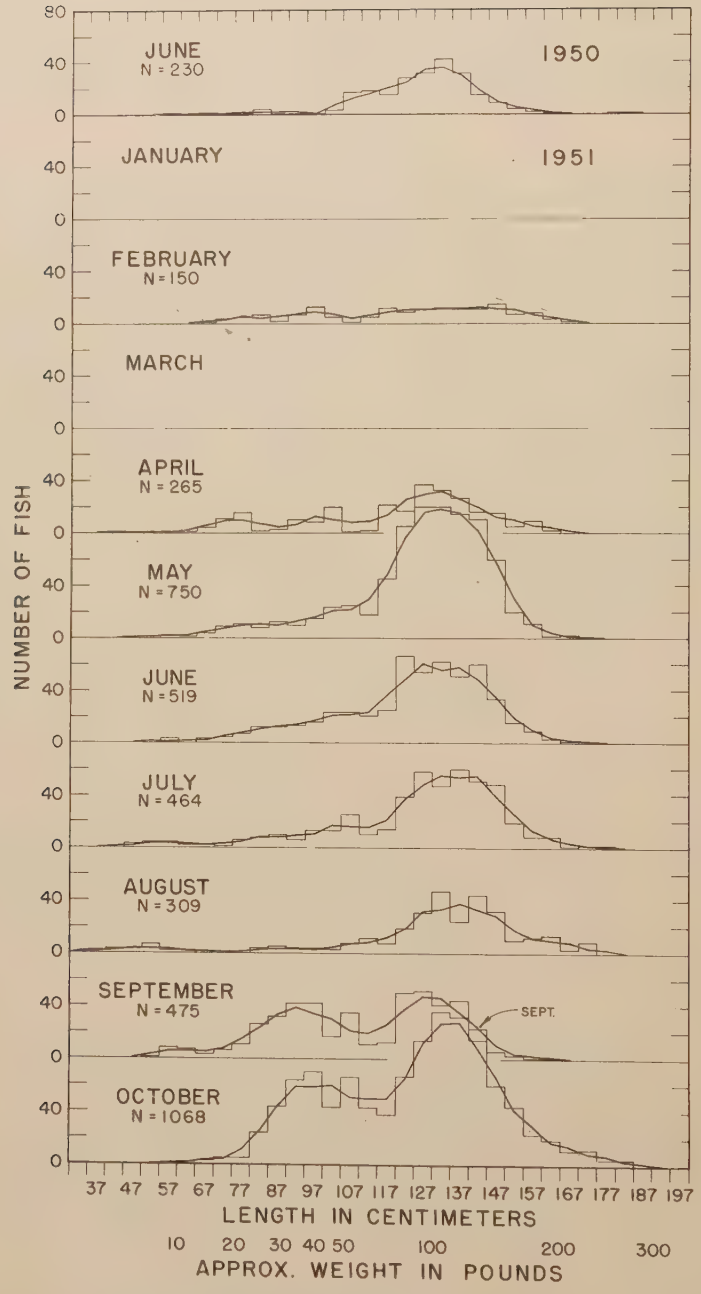


Figure 16.--Length frequencies of bigeye tuna measured during the Japanese mothership expeditions, 140°- 179°E. longitude.

separated fisheries (Hawaiian and Japanese), there is also complementary alternation of modes for a given year. Finally, it appears that once a dominant modal group enters a fishery (e.g. Hawaiian) it may be followed in that fishery for several years. Taken as a whole, these phenomena suggest that the bigeye undertake poorly understood, recurrent, and probably complex migrations.

GROWTH

Incomplete knowledge of some aspects of the life history of bigeye tuna results in a lack of understanding of the usual behavior of the dominant modes in the western and central Pacific. Hence any interpretation of the modes as year groups and interpretation of the movement of those modes as growth must be very tentative.

It is readily apparent from the weight frequency curves covering the period November 1947 through December 1954 in the Hawaiian fishery that clear-cut modal progression is displayed by bigeye tuna (figs. 4-11, table 2). Figure 13, which shows these dominant modes fitted with straight lines, indicates the apparent rate of growth. Table 4 lists the average annual weight increase of these groups as determined from the "growth lines." Assuming that the progression of the modes represents growth, these size groups increase as much as 40-50 pounds in one calendar year. Judging from the slope of the growth curves (fig. 13) and the maximum sizes attained by Hawaiian bigeye, about 6 or 7 years would seem to be a fair estimate of the life span of the species in Hawaii.

However, in the equatorial region the description of growth by the modal progression method is not feasible, since it appears that dominant modes in the size distribution do not progress.

Table 4.--Estimated increase in weights of modes from Hawaiian bigeye tuna distributions

Year	Position of modes (pounds)		Annual increase (pounds)
	January 1	December 31	
	Group A		
1949	110	145	35
1950	145	170	25
1951	170	185	15
	Group B		
1950	80	105	25
1951	105	145	50
1952	145	185	40
	Group C		
1952	90	120	30
1953	120	170	50
1954	170	195	25

SUMMARY

1. A difference in size between the sexes is exhibited by bigeye tuna in samples from the western Pacific and the Hawaiian Islands. The modes of the male size distributions are about 14 cm. or 30 pounds larger than those in female size distributions.

2. Dominant modal groups do not occur in the Hawaiian commercial catch every year, but rather exhibit a cycle that appears to have a period of about 2 years, apparently the complement of the cycle in the Japanese North Pacific fishery.

3. Homologous modes that appear during alternate years in the Hawaiian fishery are not identical in size; rather they increase slightly in size with each recurrence.

4. Approximately similar growth rates and the presence of approximately 2-year cycles of dominant size groups in the catches of both the Hawaiian fishery and the Japanese North Pacific fishery suggest there is a relationship between the bigeye tuna of the two areas.

5. A plot of bigeye weight frequencies by months from the Honolulu market for the period November 1947 through December 1954 reveals modes that progress consistently from smaller to larger sizes.

6. A provisional growth curve plotted by connecting modes found in these size distributions indicates that Hawaiian bigeye may gain as much as 50 pounds in 1 year and may live about 6 or 7 years.

7. In the vicinity of the Equator bigeye modes do not progress with time.

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APPENDIX

Table 5.--Weight frequencies of Hawaiian bigeye, Honolulu market, May-August 1951

Class intervals	Male	Female
lbs.		
50-59	-	1
60-69	1	-
70-79	-	1
80-89	-	1
90-99	-	3
100-109	2	2
110-119	9	10
120-129	8	8
130-139	9	3
140-149	8	-
150-159	9	8
160-169	17	15
170-179	13	11
180-189	13	13
190-199	15	6
200-209	9	8
210-219	9	7
220-229	10	4
230-239	7	1
240-249	8	-
250-259	1	1
260-269	2	-
270-279	1	-
280-289	1	-
290-299	1	-
Total	153	103

Table 6.--Length frequencies of equatorial bigeye by sexes, 5th Japanese mothership expedition March 29-May 28, 1951

Class intervals	Males	Females	Class intervals	Males	Females
cm.			cm.		
50-51	-	2	110-111	1	4
52-53	-	-	112-113	4	9
54-55	-	-	114-115	3	7
56-57	-	1	116-117	10	12
58-59	1	-	118-119	17	9
60-61	-	-	120-121	21	21
62-63	-	3	122-123	33	19
64-65	-	1	124-125	29	15
66-67	1	1	126-127	24	20
68-69	1	2	128-129	30	18
70-71	2	5	130-131	34	19
72-73	1	6	132-133	34	20
74-75	-	11	134-135	28	16
76-77	4	3	136-137	41	7
78-79	5	2	138-139	34	10
80-81	1	3	140-141	30	8
82-83	3	3	142-143	49	1
84-85	2	4	144-145	34	7
86-87	4	3	146-147	36	3
88-89	2	4	148-149	19	-
90-91	4	1	150-151	14	1
92-93	3	5	152-153	7	2
94-95	6	4	154-155	10	1
96-97	4	4	156-157	1	1
98-99	4	5	158-159	5	1
100-101	4	1	160-161	3	-
102-103	6	4	162-163	3	-
104-105	11	5	164-165	2	-
106-107	6	3	166-167	3	-
108-109	11	1			
Total				645	318

Table 7.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1947

Class intervals	Nov.	Dec.
lbs.		
30-39	1	1
40-49	1	5
50-59	-	-
60-69	-	4
70-79	4	6
80-89	2	12
90-99	2	14
100-109	7	8
110-119	15	20
120-129	16	39
130-139	25	56
140-149	21	58
150-159	22	41
160-169	21	18
170-179	24	26
180-189	21	29
190-199	34	32
200-209	18	47
210-219	24	42
220-229	16	34
230-239	10	23
240-249	8	23
250-259	11	12
260-269	6	8
270-279	3	1
280-289	6	4
290-299	4	1
300-309	-	3
340-349	1	-
Total	323	567

Table 8.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1948

Class intervals	Month											
lbs.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
20-29	-	-	-	1	-	-	-	-	-	1	-	3
30-39	-	-	-	-	-	-	-	-	-	1	1	3
40-49	-	3	1	1	-	-	-	-	3	-	1	4
50-59	-	3	1	3	-	-	-	2	-	1	1	3
60-69	3	-	1	-	-	1	-	-	2	3	5	12
70-79	2	12	3	1	-	1	-	1	6	4	7	15
80-89	5	10	8	3	-	-	-	2	4	5	14	20
90-99	10	23	7	12	3	4	1	1	11	9	22	46
100-109	2	11	10	12	3	3	2	2	11	9	19	57
110-119	3	18	7	16	7	2	6	-	6	7	15	27
120-129	12	40	20	34	7	3	2	3	6	15	20	19
130-139	23	72	43	54	16	3	2	4	5	15	24	31
140-149	11	81	48	72	24	2	4	3	9	14	17	34
150-159	15	61	36	55	21	12	7	5	6	21	18	39
160-169	12	47	29	26	17	11	5	5	8	14	26	35
170-179	6	26	26	28	16	12	3	2	7	12	22	30
180-189	8	37	27	26	21	15	6	2	6	12	16	21
190-199	13	21	19	35	16	20	8	2	6	7	12	12
200-209	11	34	21	15	22	18	5	2	3	12	9	12
210-219	8	22	14	13	7	11	3	2	4	5	3	10
220-229	12	16	14	5	14	11	3	2	4	6	12	8
230-239	3	9	8	6	6	7	3	1	1	5	8	5
240-249	-	6	3	3	5	3	3	1	1	5	6	7
250-259	2	2	3	4	2	3	3	1	1	4	7	2
260-269	1	4	-	1	1	1	-	-	3	-	3	2
270-279	1	3	3	3	-	1	-	-	-	2	2	3
280-289	2	1	1	1	-	-	-	-	-	-	1	1
290-299	2	4	3	-	-	-	1	-	-	-	-	2
300-309	-	-	-	-	-	-	-	-	1	1	-	-
310-319	-	-	1	-	-	-	-	-	-	-	-	-
320-329	-	1	-	-	-	-	-	-	-	-	-	1
330-339	-	-	-	-	-	-	-	-	-	1	-	-
Total	167	567	357	430	208	144	67	43	114	191	291	464

Table 9.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1949

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
10-19	-	-	-	-	-	-	-	-	-	-	-	2
20-29	-	1	1	-	1	-	-	-	-	1	-	-
30-39	-	1	1	1	1	-	-	-	-	2	6	9
40-49	-	3	3	-	1	-	-	-	-	2	9	24
50-59	-	2	4	-	-	1	-	-	-	1	4	18
60-69	-	3	1	-	-	-	-	1	2	8	5	20
70-79	-	7	2	2	2	-	-	1	-	11	10	18
80-89	-	9	4	2	5	1	-	-	-	3	7	21
90-99	6	24	43	12	12	1	-	-	2	3	3	21
100-109	10	47	47	27	34	7	3	1	1	3	11	12
110-119	5	29	50	28	31	10	6	6	7	9	19	36
120-129	6	15	36	33	37	16	3	8	10	13	44	97
130-139	5	19	28	21	38	16	4	6	11	24	82	202
140-149	8	14	30	25	33	13	8	5	20	25	81	205
150-159	16	19	28	16	37	10	5	2	10	27	74	166
160-169	6	25	33	22	36	9	5	2	11	24	52	133
170-179	9	29	18	35	40	12	5	4	9	31	54	106
180-189	4	22	26	31	30	16	3	4	3	27	48	121
190-199	7	12	26	23	18	8	2	3	7	18	51	74
200-209	3	18	10	18	23	12	6	3	4	19	37	67
210-219	8	11	8	13	11	12	6	7	6	16	42	74
220-229	15	6	7	7	11	9	11	4	7	18	27	49
230-239	4	13	2	5	3	7	6	7	7	9	23	30
240-249	4	5	2	4	3	6	2	3	2	9	12	18
250-259	4	3	3	1	2	4	4	1	1	3	9	15
260-269	3	3	1	-	2	2	2	3	-	4	6	15
270-279	1	3	-	-	1	-	-	4	2	3	9	7
280-289	1	-	-	-	-	-	-	-	1	1	3	3
290-299	-	-	-	-	-	-	-	1	1	-	3	-
300-309	-	-	-	-	-	-	-	-	1	1	3	1
310-319	-	-	-	-	-	-	-	-	1	-	-	1
320-329	-	1	-	-	-	-	-	-	-	1	1	1
330-339	-	-	-	-	-	-	-	-	-	1	-	1
340-349	-	-	-	-	-	-	-	-	-	-	-	-
350-359	-	-	1	-	-	-	-	-	-	-	-	-
Total	125	344	415	326	412	172	81	76	126	317	735	1567

Table 10.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1950

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
0-9	-	-	-	-	-	1	-	-	-	-	-	-
10-19	-	-	-	1	3	8	9	14	-	1	-	1
20-29	-	2	-	1	-	4	4	15	-	-	4	2
30-39	1	3	-	9	7	4	6	2	4	7	9	8
40-49	4	5	2	2	5	-	4	3	-	3	7	10
50-59	3	7	8	9	2	2	3	1	1	4	5	11
60-69	5	13	10	16	7	4	9	3	5	18	15	9
70-79	10	21	18	18	23	10	7	6	9	37	27	38
80-89	13	43	10	14	25	22	10	14	19	38	62	79
90-99	7	24	16	34	25	16	16	13	12	40	71	130
100-109	6	12	8	33	41	19	21	9	19	27	58	130
110-119	14	26	20	26	38	23	22	5	16	28	49	78
120-129	26	66	38	71	86	51	12	15	11	26	37	66
130-139	49	108	77	113	157	77	38	12	12	19	42	76
140-149	68	139	80	140	200	97	51	27	20	29	29	56
150-159	42	72	59	123	148	102	88	42	29	58	53	90
160-169	32	61	45	99	126	100	75	56	33	57	78	136
170-179	30	50	38	56	108	85	65	51	22	72	100	176
180-189	38	38	42	47	75	83	72	27	12	61	81	172
190-199	24	35	31	60	79	84	46	28	13	40	69	128
200-209	13	41	23	46	61	62	44	31	17	36	45	109
210-219	12	25	15	41	53	54	30	13	2	25	41	62
220-229	7	27	11	29	35	42	14	19	7	22	35	58
230-239	10	22	6	21	19	24	25	13	7	12	21	52
240-249	8	8	5	10	21	10	5	9	5	11	15	30
250-259	4	5	6	10	9	8	9	7	2	5	13	19
260-269	4	8	4	3	4	3	7	1	-	7	7	18
270-279	-	3	1	2	1	5	5	3	1	6	6	13
280-289	1	1	1	1	1	1	3	3	2	2	2	7
290-299	1	-	1	-	-	-	-	-	-	1	3	6
300-309	-	-	-	-	-	-	1	-	-	3	4	1
310-319	-	-	1	-	-	-	-	-	-	2	1	3
320-329	-	-	-	-	-	-	-	-	-	1	1	2
330-339	-	-	-	-	-	-	-	1	-	-	-	-
Total	432	865	576	1035	1359	1001	701	443	280	698	990	1776

Table 11.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1951

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
20-29	-	-	1	-	-	-	-	-	-	1	-	-
30-39	2	-	2	-	-	1	-	-	-	2	2	5
40-49	3	1	5	1	2	1	1	1	-	8	3	8
50-59	1	-	10	12	3	1	3	1	1	6	2	12
60-69	3	3	2	3	2	5	3	6	12	10	3	14
70-79	2	8	5	3	1	-	2	2	18	40	15	15
80-89	23	32	26	12	14	-	-	3	2	34	17	33
90-99	43	65	37	30	17	14	1	2	9	17	6	21
100-109	37	40	71	57	53	24	10	11	14	20	8	15
110-119	22	48	63	82	75	40	25	24	15	34	20	31
120-129	17	18	43	86	51	26	29	19	36	80	43	52
130-139	17	13	44	62	58	21	37	19	47	113	82	112
140-149	21	19	56	79	59	21	25	8	44	103	130	221
150-159	24	32	72	103	84	31	34	18	31	89	110	256
160-169	40	55	59	91	93	43	25	16	23	51	63	186
170-179	33	39	80	108	63	34	28	28	18	63	51	116
180-189	29	37	47	78	78	38	40	22	32	49	63	88
190-199	36	27	28	44	61	38	27	17	20	45	60	97
200-209	13	31	17	33	45	25	27	11	18	45	69	90
210-219	14	12	15	22	34	23	19	5	13	31	48	83
220-229	15	15	7	12	24	11	14	7	12	22	43	45
230-239	9	9	5	6	21	11	10	4	4	19	32	40
240-249	7	14	2	7	12	12	14	2	4	11	23	22
250-259	4	6	3	2	3	2	3	1	1	8	20	23
260-269	2	-	1	4	4	3	2	1	1	4	9	10
270-279	1	-	1	2	1	-	1	1	-	6	5	8
280-289	1	1	2	-	-	1	1	2	1	3	3	7
290-299	-	2	-	-	1	1	1	-	1	1	1	3
300-309	-	-	-	-	-	-	-	-	-	1	1	2
310-319	-	-	-	-	-	-	-	-	-	-	-	1
Total	419	527	704	939	859	427	382	231	377	916	932	1616

Table 12.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1952

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
20-29	-	-	1	-	-	-	-	-	-	-	-	-
30-39	1	2	-	1	-	-	-	-	-	1	3	3
40-49	4	11	4	2	1	-	-	-	-	-	1	5
50-59	21	33	14	1	1	-	-	-	-	4	2	4
60-69	15	17	15	8	1	-	-	1	1	1	1	9
70-79	9	15	14	3	4	1	1	1	4	7	4	9
80-89	34	25	11	4	3	-	1	2	11	27	18	25
90-99	46	34	14	9	16	2	4	1	13	29	44	75
100-109	29	34	15	12	28	9	10	7	14	28	54	128
110-119	21	32	18	33	39	10	14	8	11	37	66	134
120-129	34	55	52	56	35	14	10	10	14	43	60	145
130-139	67	119	89	105	71	14	5	9	15	22	42	132
140-149	99	163	136	166	97	17	21	20	16	40	34	70
150-159	93	124	131	207	145	26	11	23	22	25	44	92
160-169	68	75	73	182	99	24	19	26	22	52	51	104
170-179	34	62	68	129	112	26	26	35	52	66	67	115
180-189	28	68	62	76	70	24	21	25	34	75	74	131
190-199	32	58	58	76	65	18	21	16	28	68	76	123
200-209	22	64	47	83	66	20	13	14	25	57	54	82
210-219	22	33	33	44	50	23	10	6	15	44	48	50
220-229	15	23	26	43	34	17	5	3	9	40	28	39
230-239	15	14	16	16	31	6	6	5	4	26	24	26
240-249	10	13	12	8	14	5	2	6	8	25	15	23
250-259	3	6	8	7	3	3	2	2	3	16	23	13
260-269	2	9	6	6	6	2	-	-	-	9	11	17
270-279	1	7	3	2	2	2	-	1	-	6	6	3
280-289	1	3	1	1	1	2	-	2	-	2	6	3
290-299	3	-	1	2	1	-	-	-	2	-	4	1
300-309	1	3	-	2	-	-	-	-	-	1	2	-
310-319	-	-	-	-	-	-	-	-	-	-	4	1
320-329	-	-	-	-	-	-	-	-	-	-	-	-
330-339	-	-	-	-	-	-	-	-	-	-	-	-
340-349	-	-	-	-	-	-	-	-	-	-	1	-
350-359	-	-	-	-	-	-	-	-	-	-	1	-
360-369	-	-	-	-	-	-	-	1	-	-	-	-
380-389	-	-	-	-	-	-	-	-	1	-	-	-
Total	730	1102	928	1284	995	265	202	224	324	751	868	1562

Table 13.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1953

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
10-19	2	-	-	-	-	-	-	-	1	-	-	-
20-29	1	-	2	1	-	-	-	-	-	4	-	-
30-39	1	4	2	-	-	-	-	-	3	9	-	3
40-49	1	4	8	1	-	-	-	-	8	13	-	5
50-59	3	3	2	6	-	-	-	-	-	7	1	8
60-69	-	1	-	-	-	-	-	2	2	3	1	7
70-79	-	1	4	1	1	1	1	-	-	6	4	20
80-89	5	17	15	3	-	-	-	-	3	3	7	21
90-99	11	49	40	11	3	-	1	1	-	-	-	5
100-109	27	65	77	23	14	1	6	4	-	1	2	6
110-119	41	111	81	51	34	11	10	6	7	7	5	12
120-129	31	118	107	72	89	22	22	10	3	14	14	17
130-139	15	63	73	73	85	38	24	5	14	23	17	34
140-149	14	76	54	55	70	38	29	18	16	29	28	57
150-159	8	62	57	42	52	29	38	20	33	49	61	99
160-169	15	57	52	49	53	22	32	17	35	45	82	143
170-179	11	78	54	46	68	36	24	13	30	46	80	118
180-189	10	62	52	51	71	31	34	16	18	26	56	78
190-199	14	54	36	41	62	41	28	9	24	21	28	58
200-209	5	50	25	35	61	42	26	11	12	19	34	33
210-219	6	25	17	15	53	22	17	11	5	21	31	21
220-229	7	14	20	17	36	21	11	4	4	12	22	19
230-239	2	8	7	11	14	8	9	3	1	13	16	16
240-249	5	12	4	5	11	5	7	3	5	7	13	11
250-259	1	5	2	1	7	3	1	1	-	5	4	7
260-269	2	6	3	1	4	-	3	-	1	4	4	4
270-279	1	4	-	-	3	2	1	-	1	4	5	3
280-289	-	-	2	-	2	-	-	3	-	2	2	1
290-299	1	2	-	-	-	-	-	-	-	-	5	-
300-309	-	3	-	-	-	-	-	-	-	-	-	-
310-319	-	-	-	-	-	-	-	-	-	1	-	-
320-329	-	-	-	-	-	-	-	-	-	-	1	-
340-349	-	1	-	-	-	-	-	-	-	-	-	-
Total	240	955	796	611	793	373	324	157	226	394	523	806

Table 14.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1954

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
20-29	-	-	-	-	-	-	-	-	1	-	-	-
30-39	1	-	-	1	-	-	-	-	-	4	2	-
40-49	3	3	-	1	-	-	-	-	-	3	11	11
50-59	-	3	1	3	-	-	-	-	-	2	15	16
60-69	1	6	2	4	-	-	-	-	-	4	5	4
70-79	8	16	-	-	2	-	-	-	5	10	8	7
80-89	10	15	9	2	-	-	-	1	2	17	17	12
90-99	11	21	9	7	5	1	-	-	-	9	25	28
100-109	8	21	13	16	5	3	-	-	6	8	16	34
110-119	3	9	12	28	9	3	-	4	8	15	14	33
120-129	6	11	9	19	6	3	-	2	9	21	31	37
130-139	12	18	5	12	18	3	-	1	8	23	27	49
140-149	15	30	17	35	18	8	1	-	6	26	29	61
150-159	30	59	30	64	36	4	1	1	8	12	30	66
160-169	37	82	66	79	66	16	4	3	9	23	31	52
170-179	29	60	43	132	59	18	3	4	7	25	29	52
180-189	20	52	47	111	41	17	6	4	10	24	36	45
190-199	10	37	30	74	39	10	3	1	12	28	33	53
200-209	12	35	21	56	24	12	6	3	7	22	40	84
210-219	5	27	14	46	13	2	4	4	12	26	33	67
220-229	7	11	22	32	17	2	-	2	2	13	33	39
230-239	6	12	9	19	4	1	-	6	2	15	17	21
240-249	3	8	6	14	5	6	-	1	4	7	16	13
250-259	4	3	3	7	4	1	1	1	3	4	8	14
260-269	-	3	4	8	-	1	2	-	2	7	3	2
270-279	1	4	2	3	1	2	-	-	1	-	-	5
280-289	-	2	-	-	-	-	-	-	-	5	4	1
290-299	-	1	-	-	-	-	-	-	-	-	3	-
300-309	1	-	1	-	-	-	-	-	-	-	-	-
310-319	-	1	-	-	-	-	-	-	-	1	1	-
320-329	-	-	-	-	-	-	-	-	-	1	-	-
330-339	-	1	-	-	-	-	-	-	-	-	-	-
Total	243	551	375	773	372	113	31	38	124	355	517	806

AG LARGE YELLOWFIN—Two men landed all fish, retrieved buoys, and put droppers on racks. Photograph by G. I. Murphy

By EDWIN S. IVERSEN
and
GARTH I. MURPHY

The authors are fishery research biologists on the staff of Pacific Oceanic Fishery Investigations, who accompanied the vessels on the trips which they discuss.

It is noteworthy that the **North American** was reported wrecked on Point Loma, near San Diego, early in November, 1954.

What the Jangaard Longline enture Found in Mid-Pacific

uring a recent commercial fishing of central Pacific tuna waters by Vest Coast fishing boats, a total of 210 tons of Yellowfin tuna landed at Honolulu and San . This fishing was done in equa- grounds previously explored by ch ships of the Pacific Oceanic ery Investigations (POFI), a h of the U. S. Fish and Wildlife ce in Hawaii. These commercial ls, under contract with the Serv- vere given financial assistance to ase fishing gear and make vessel tions, and the fishermen under- to test thoroughly the commercial bilities of this potential fishery two vessels to fish tuna longlines total of four trips. POFI biolo- were aboard the boats on both f trips, and the following account sed on their observations.

IRST CRUISES—On the evening nuary 12, 1954, the *North Amer-* an 86′ bait boat skippered by . Sverre Jangaard, and the *Alrita,* ′ combination boat captained by . Lars Jangaard, departed San o for the tuna grounds near the tor in the vicinity of Christmas d.

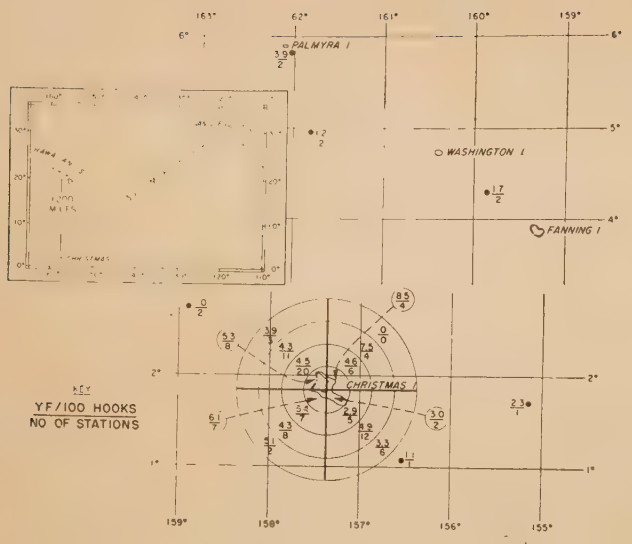
ter about a month of fishing the two vessels put in at Honolulu, where they unloaded 103 tons of Yellowfin tuna at Hawaiian Tuna Packers, Ltd. Over 4 tons of market fish, including marlin, Bigeye, wahoo, and shark, was sold fresh at varying prices on the local market.

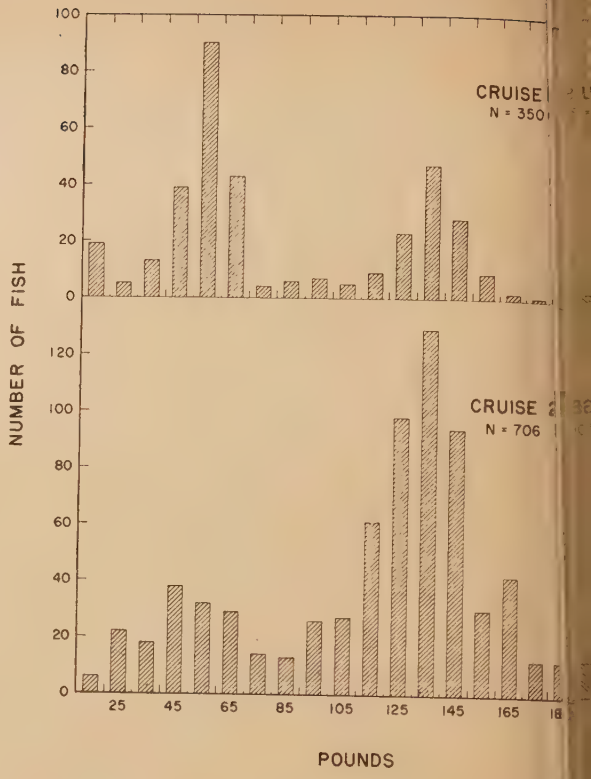
In all, the *Alrita* fished 31 days and the *North American* 30 days during the period January 27 to February 28, although the first few days of fishing were spent mainly in experimenting with the gear and methods of handling it. Once the vessels settled down to serious fishing, they averaged 57 baskets (855 hooks) of longline gear per day for the first set of cruises.

It is significant that on all but two or three days the two boats fished near each other. It had been planned originally that they would keep close company only during the first few days, while the fishermen were familiarizing themselves with this type of fishing. From the outset, however, difficulties arose in the form of numerous breaks in the main lines due to the use of excessively lightweight fiber line and to the setting of gear across current rips in unfamiliar waters; for these and other reasons the two boats continued to fish within sight of each other. Somewhat of a handicap was thus imposed, for had the vessels separated during those periods when fishing was poor, they would have been able to scout a greater area, possibly increasing their catch by more rapidly finding new concentrations of fish.

• *TWO TYPES OF FISH*—Generally, the Yellowfin consisted of two size groups. The smaller averaged about 55 lbs. and were designated "school fish" since their capture was always accompanied by signs of Yellowfin at the surface. The other group of fish averaged about 135 lbs. and were recognized as "deep-swimming Yellowfin," in that they were not seen at the surface and were captured both with and without surface signs of fish.

There was considerable fluctuation in the catches from day to day, but underlying these short-term variations there seemed to be three different periods in the fishing. The first, from January 27 to February 8, afforded moderately good fishing, with the best daily catch per boat amounting to about 3 tons. The second period, from February 9 to 15, saw very good fishing, with a high day's catch of 9 tons





Where They Fished— And What They Caught

by the *North American.* Finally, catches dropped back again to the earlier level, with the best catches ranging up to 3 tons. During the two periods of moderately good fishing the catch comprised large numbers of "school fish" with moderate numbers of "deep-swimming tuna." During the middle part of phenomenally good longline fishing the Yellowfin population around Christmas Island appears to have been augmented by an influx of large numbers of "deep-swimming tuna" that later left the area.

Summarizing the catch of the first trip to the equatorial grounds, in 30 fishing days the two vessels combined captured 2,512 Yellowfin tuna weighing 206,110 lbs. The average daily catch was 1.75 tons of saleable Yellowfin per vessel.

In addition to the 103 tons of Yellowfin that was delivered to the cannery, there were 298 Yellowfin damaged by sharks. Some of these were completely consumed except for the head, but others that were only slightly damaged were delivered to Honolulu and sold on the fresh fish market. The tuna delivered to Hawaiian Tuna Packers was processed into solid, chunk, and grated packs. Most of the fish were satisfactory for these standard packs, but in the judgment of the canners some were unsuitable and a 15% deduction was assessed against the loads. Most of the rejected fish were judged by Hawaiian Tuna Packers to be either too dark or too "green" for a light meat pack.

• *GEAR OPERATED*—The amount of gear fished was remarkable, considering that there were only seven men aboard each of the vessels. Because of the numerous breaks in the main lines, the captains did not want to chance having inadequately lighted gear out after dark, and the small number of buoy lights available, four on each vessel, was partly responsible for the limitation of the size of sets to a maximum of 70 baskets of longlines. Furthermore, the long baskets (1,620′ main lines with 15 hooks) offered more resistance to the water than the 1,260′ main lines and 11 hooks of the baskets normally fished by POFI research vessels; thus hauling was slower, averaging 26 seconds per hook as compared with 20 seconds per hook with POFI gear.

The gear used by the Jangaards was an adaptation of the most recent type of longline developed by POFI, the only essential difference being the longer main line and the increase in the number of branch lines from 11 to 15. One reason for lengthening the main line was to make the gear fish deeper; POFI results show that often the deeper hooks catch the most Yellowfin. During this cruise 46% of the Yellowfin were taken on the five deepest hooks, apparently justifying the increased main line length. However, the long baskets were h haul because of their greater v This put more strain on the lin the winch and appeared to slow the hauling process, particularly several fish were caught on a basket.

The gear was set and hauled i tually the same manner as use Japanese fishermen and aboard vessels, except that one signi modification permitted a crew of seven men to carry out the operation. (The Japanese use 30 and POFI uses 9 or 10). Thi the practice of not coiling the dro in with the main line when the ba were retrieved. The branch lines made as short as possible, on fathom of cotton line and 1 fat of wire leader, and a rack was de that would hold 60 branch lines keep them clear during stowage. ing hauling, the branch lines stowed on these racks as they unsnapped from the main line, the main lines were stowed in ca skates. In stowing the main lines metal links to which branch and f lines are attached were arranged they could be easily found. On sett the gear was assembled as the m line paid out, branch lines and f lines being snapped in as needed. T system called for more work dur setting than if the branch lines w left snapped-in and coiled down w the main lines, but it considera lessened the work during the crit

period.
resh-frozen Alaska herring
bait were double hooked,
he eye and back through the
in order to reduce the loss
uring the soaking period.

ND CRUISES—After selling
catches in Honolulu, the two
uelled, provisioned, and sailed
March 13 for the Line Islands
hing began on March 18 and
tinued for 20 days by the
d for 40 days by the *North*
n. On April 7 the *Alrita* de-
Christmas Island and arrived
olulu on April 15 while the
American departed Christmas
April 28 and arrived at San
n May 15. There were no
in the gear or fishing methods
econd set of cruises. The aver-
nbers of baskets set per day
(945 hooks) for the *Alrita*
(930 hooks) for the *North*
in.

otal catch of the *North Ameri-*
this trip consisted of 1,728
in, 8 Bigeye, 64 Skipjack, 8
e, 41 black marlin, 511 shark,
few miscellaneous fish. Tuna
at San Diego amounted to 72
he *Alrita* caught 689 Yellow-
Skipjack, 9 Albacore, 7 Big-
black marlin, 216 shark, and
miscellaneous fish. Of the 35
tuna and about 7 tons of mar-
ded at Honolulu by the *Alrita,*
10 tons of Yellowfin and some
marlin had been transferred
he *North American* when it be-
necessary for the smaller vessel
e the fishing grounds after 20
f fishing. The *North American*
h average catch rate of 4.4 Yel-
per 100 hooks per day. Of her
wfin catch, 248, or about 14%,
mutilated by sharks. The *Alrita*
ed 3.6 Yellowfin per 100 hooks
ad 12% of them damaged by

eneral no such difference in the
e of fish by the deep and shal-
ooks, as was seen on the first
s, could be detected. The catch
llowfin per 100 hooks at the
tations away from the island was
(averaging 1.9 fish per 100
), and no particular area in the
ty of the island seemed better
any other. The Yellowfin catch
ared to consist of at least two
groups, one weighing about 50
nd the other about 130 lbs. The
ge weight of all Yellowfin taken
e cruise is estimated at 110 lbs.
males were captured than fe-
, the ratio being 54% males to
females when all sizes are con-
ed.

Alrita's catch was sold in Hon-

SETTING LONGLINE on the **Alrita.** The coiled mainline was set under the chute and allowed to pay out with slack thrown periodically by hand. The man on the left handled buoys and poles. The three men on the right cleared, baited, and snapped on droppers. Photograph by G. I. Murphy.

olulu to Hawaiian Tuna Packers. Of the approximately 70,000 lbs. of Yellowfin landed, the deduction to the fishermen was 6,109 lbs. or a 9% loss. A large portion of the catch was packed as smoked tuna. Although the fresh market demand was poor, some of the market fish were sold locally.

The *North American's* catch was landed at the Van Camp Sea Food Company in San Diego, Calif. The cannery reported the weight as 144,316 lbs., including a few shark-damaged fish. Rejections of cooked and cleaned fish by the cannery were observed; no honey-combing was seen, the majority of the rejects being "green" and a lesser amount too dark in color. The total deduction was 36,162 lbs. or about 25% of the load. The catch was packed as "bite size" with the exception of a very small portion that was put up as flakes.

The weight of fish delivered constituted a capacity load for each vessel. The large Yellowfin did not stow handily so cargo space utilization was poor, and furthermore some of the brine tanks were needed to hold fuel for the *North American's* return trip to San Diego.

Two Gilbertese natives from Christmas Island, one of whom spoke English, were employed when one of the *North American's* fishermen left the ship. They were paid $2.60 for 8 hours work, after which they are entitled to overtime. Employment is being sought for these people and the Christmas Island Plantation encourages their use.

The *Alrita's* fishermen shared about $2,100 for 51 days of fishing or 93 days at sea. Shares on the *North American* were about $3,100 for 70 fishing days or 117 days at sea. Without government aid the *Alrita* shares would have been around $1,100 and those of the *North American* about $1,700.

● *WHAT WAS LEARNED*—In unfamiliar waters the seven-man crews from these two vessels successfully adopted a fishing technique heretofore used only by Japanese on vessels with 20 to 40 fishermen. On the first set of cruises each of the vessels averaged about 1.75 tons of Yellowfin per day of fishing and on the second set about 1.78 tons. There was an increase in the average weight of the Yellowfin captured from 80 lbs. on the first cruises to 110 lbs. on the second set. Although it has not always been the case on POFI research cruises, the commercial boats found better fishing close to Christmas Island (within 60 miles) than at greater distances. The variability of the catch from day to day was so great that it was not possible to detect any clearly superior fishing grounds around the island. No fishing time was lost because of bad weather during the entire period of these cruises.

From these results it is to be concluded that it is commercially practicable for American fishing boats, using reasonably small crews, to fish Yellowfin tuna in the equatorial central Pacific by the longline method.

Annotated List of Birds Observed on Christmas Island, October to December, 1953

JOSEPH E. KING

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January, 1955

Annotated List of Birds Observed on Christmas Island, October to December 1953

JOSEPH E. KING[1]

IN OCTOBER 1953, the Pacific Oceanic Fishery Investigations of the U. S. Fish and Wildlife Service landed a small field party (the author and Mr. Richard Shomura) on Christmas Island for the purpose of installing weather instruments and sea thermographs, and to conduct a tuna bait-fish survey of the lagoon. We were on the island from October 23 to December 9, 1953, and although our time was generally occupied with the duties mentioned above, we had many opportunities to observe the interesting bird life of the island. As Christmas and other islands of the Line Island group (Fanning, Washington, and Palmyra) are rarely visited by ornithologists, we thought it worthwhile to report our observations.

The author is indebted to Dr. Frank Richardson for his helpful review of the manuscript.

Christmas Island (Fig. 1), lies in the equatorial Pacific about 1,200 miles south of Hawaii at 2° N. latitude, 157° W. longitude. It is about 35 miles in length, in a northwest–southeast direction, and about 17 miles in width. The island is a large coral atoll with a perimeter of about 105 miles. Enclosed within the outer coast is an area estimated at 382 square miles, of which approximately 250 are land and 107 are lagoon; about 25 square miles are occupied by numerous salt lakes (Wentworth, 1931). The island is generally low, averaging about 10 feet or less in t tion, except along the southern shore c Bay of Wrecks where there are scattered dunes which may reach 40 feet in heigh

The rainfall is quite variable but ave 25 to 35 inches a year (Bryan, 1942). mentary records show an annual range 10 inches to as much as 100 inches. Th temperature varies from a minimum of or 70° F. to a maximum of 106° F. (W worth, 1931).

Christophersen (1927) records 24 spe of vascular plants as growing naturally Christmas Island. These include *Tournef argentea* trees, clumps of *Scaevola frutescens* other low shrubs, grasses, and herbs. though all the coconut palms now seen on island have been planted, there were a palm trees present at the time of Capt Cook's visit in 1777. There are now extens coconut groves in the northwestern, northe southwestern, and southern parts of island.

The vertebrate fauna of the island cons mainly of the fishes that abound in the lag and coastal waters and the abundant bird that forms the subject of this report. In ad tion there are lizards, rats, and cats; many the latter roam in a wild state, and while t may help keep down the rat population, t also without doubt prey on the grou nesting birds.

Great Britain claims sovereignty over island and has brought in natives from Gilbert and Ellice Colony to provide a la

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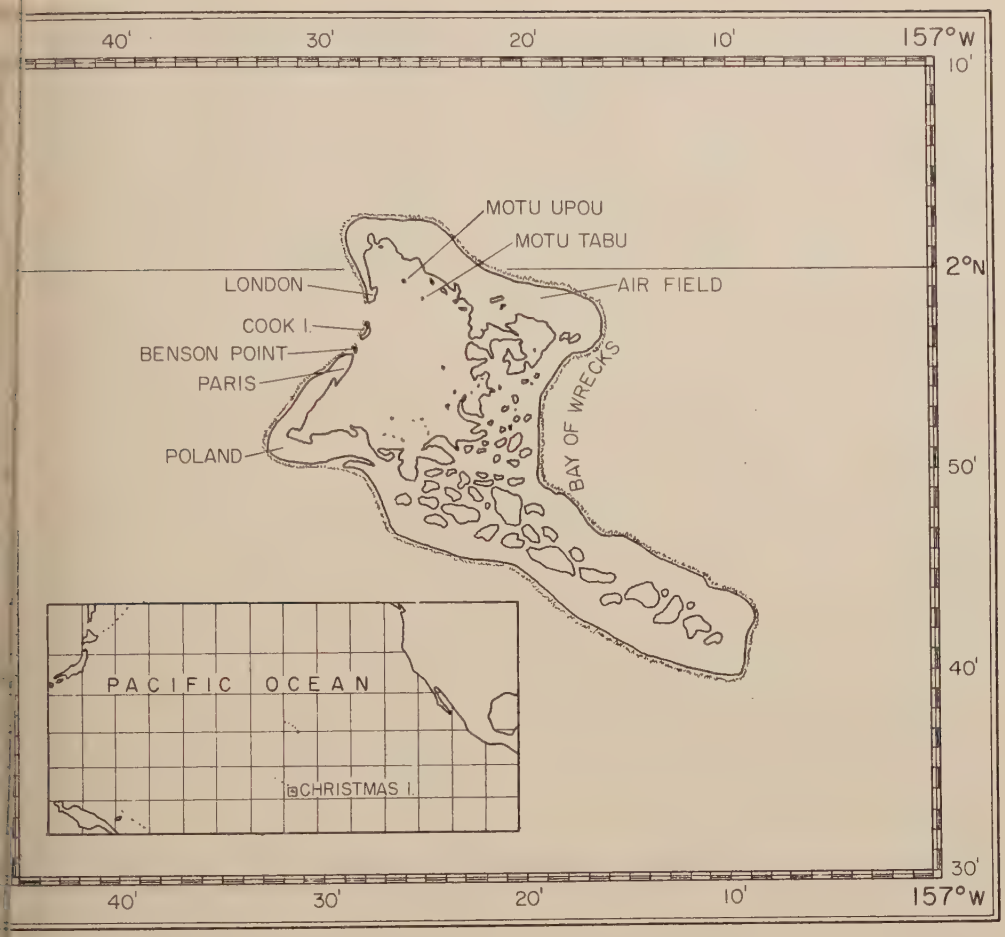

. 1. Christmas Island, showing locations referred to in the text and the island's general position in the central (inset). (Drawn with modifications from USN Hydrographic Office Chart No. 1839.)

for the plantation. There is no indi- us population.

review of the literature describing the una of Christmas Island begins with the unt of its discoverer, Captain James Cook. he afternoon of December 24, 1777, Cap- Cook brought his ships the "Resolution" the "Discovery" to anchor off the west e of the island. On the next day—Christ- Day—he and his men went ashore at k Island (Fig. 1), a small patch of coral sand separated from the main island. He s (Cook, 1784), "As we kept our Christ- here, I call this discovery Christmas Is- land." The vessels stayed at anchor several days to permit the men to refresh themselves and to observe an eclipse of the sun. Cook reports that there were no traces of human beings having been there before and that the number of coconut trees did not exceed 30. He had the following to say about the animal life *ibid.*, p. 188–189):

> Under the low trees above-mentioned, sat infinite numbers of a new species of tern, or egg-bird. These are black above, and white below, and with a white arch in the forehead [apparently sooty terns]; and are rather larger than the common noddy. Most of them had lately hatched their young, which lay under old ones, upon the bare ground. The rest had eggs; of which they only lay one, larger than that of a pigeon,

bluish and speckled with black. There was also a good many common boobies; a sort that are almost like a gannet [most likely the blue-faced booby]; and a sooty or chocolate-coloured one, with a white belly [the brown booby]. To this list we must add men-of-war birds; tropic-birds; curlews; sand-pipers; a small land-bird like a hedge sparrow [the kokikokiko, as named by the Gilbertese]; land crabs; small lizards; and rats.

The whaling ship "Tuscan" stopped at Christmas Island in May, 1835. Bennett (1840) gives an interesting account of the visit and states that, "Here and there among the low thicket scrubs are vast rookeries of aquatic birds, whose clamour is deafening." He mentions "sooty terns," "red-tailed tropic birds," "pure snow white petrels," probably white terns, "boobies," blue-faced boobies from the description, other "terns," probably noddies, "frigate birds," "petrels," "curlews," bristle-thighed curlews, "quail," probably golden plover, and a "sparrow-like land bird," the kokikokiko.

Streets (1877) visited Christmas Island in the vessel "Portsmouth" during the course of the United States North Pacific Surveying Expedition of 1873–75. Nine species of birds were reported and a collection was made. Father Emmanuel Rougier (1914), who at one time held a lease on the island, has published one of the most complete descriptions of Christmas Island, including its flora and fauna. He lists the following birds: frigate bird, sooty tern, grey-backed tern, Necker Island tern, Hawaiian tern, noddy tern, white tern, Christmas Island shearwater, red-tailed tropic bird, blue-faced booby, red-footed booby, and the kokikokiko (a small land bird), a total of 12 species. Kirby (1925) reports 11 species of sea and shore birds (including the bristle-thighed curlew, wandering tattler, and golden plover) plus several kinds of migratory ducks (which he does not name) as occurring on the island. He states that birds have been greatly reduced in number (prior to 1925) throughout the Line Islands as a result of land clearing and other disturbances by man. In 1921 the Whitney Expedition of the American Museum of Natural History carried on an investigation of the birds of Christmas Island. Specimens of the kol kiko, *Conopoderas aequinoctialis aequino* (Latham), collected at this time have described by Murphy and Mathews (19

The following is a list, with a few history notes, of the birds seen by the au during his stay on Christmas Island October 23 to December 9, 1953. In gen Peters (1931, 1934) has been followed in spect to scientific names.

Puffinus nativitatus Streets, Christmas Sh water. Abundant. Observed nesting eggs and young on the islets of Motu T and Motu Upou within the lagoon. N were in shallow tunnels or depressions o hung with grass or low shrubs.

Pterodroma alba (Gmelin), Phoenix Pe Abundant. Observed nesting with e (Fig. 2*d*) and young on the islets of M Tabu and Motu Upou. This petrel co be seen throughout the day, flying over the land and lagoon, and was m commonly seen over land than was Christmas shearwater. Nesting habits w the same as for that species.

Nesofregetta albigularis (Finsch), White-thro ed Storm Petrel. Uncommon. Obser near shore (October 22) when we were proaching the island from the north, a seen on several occasions flying over lagoon and outer beach. One bird of t species was found nesting, with one eg on the islet of Motu Tabu. The egg was a shallow depression over-hung by a thi cover of grass.

Phaethon rubricauda melanorhynchos Gmel Red-tailed Tropic Bird. Abundant. O served nesting with eggs and young (Fi 2*c*) throughout the island. Egg usually w placed under the low shrubs of *Scaevola* the larger *Tournefortia*.

Sula sula rubripes Gould, Red-footed Boob Abundant and generally distribute throughout the island. Nests with eg and young (Fig. 2*e*) were observed prin pally in *Tournefortia* trees.

G. 2. Some of the birds of Christmas Island; photographed by the author. *a*, Young white tern on the remains nest of the white-capped noddy; *b*, young white-capped noddy on the nest; *c*, red-tailed tropic bird with g; *d*, Phoenix petrel with egg; *e*, red-footed booby with young; *f*, blue-faced booby with eggs.

tified on Christmas Island during the period October 23–December 9, 1953. Of this number, 11 species were observed with eggs or with eggs and young. The author believes this to be the first report of the occurrence of the crested tern and the ring-billed gull on Christmas Island or for the Line Island area.

ADDENDUM

Since the submission of this manuscript the author has made another visit to Christmas Island, June 5 and 6, 1954. Other duties prevented a thorough survey of the Island, but through the courtesy of British District Officer Percival Roberts, a short trip was made to the islet of Motu Tabu. Species observed nesting with eggs and young were the Christmas shearwater, white-capped noddy, common noddy, white tern, and red-tailed tropic bird. The Phoenix petrel was brooding eggs, but no young were seen. The blue-grey noddy was quite abundant on the islet, but no eggs or young could be found. Sooty terns, crested terns, frigate birds, and red-footed boobies were observed flying over the lagoon. Some of the Gilbertese plantation staff informed us that the sooty terns had not yet started to nest but had already begun to congregate on the main island for their summer nesting season.

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CONSTRUCTION DETAILS OF IMPROVED TUNA LONG-LINE GEAR USED BY PACIFIC OCEANIC FISHERY INVESTIGATIONS

By Herbert J. Mann*

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This report is a description of the latest type of fiber long-line gear now being used by Pacific Oceanic Fishery Investigations (POFI) to capture tunas in the central Pacific. It is a revision of an earlier report (Niska 1953) and contains a complete description of the gear and its use, with particular attention to changes made since the earlier report was issued.

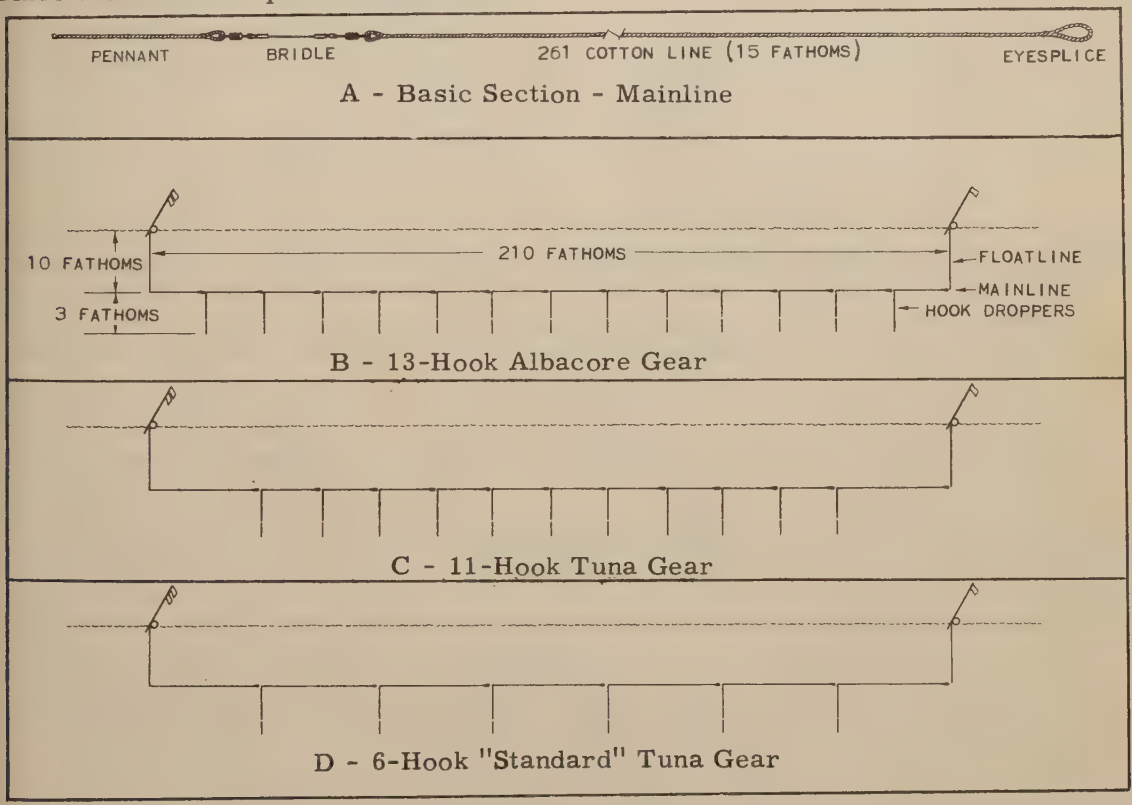

Fig. 1 - Three types of POFI long-line gear, and the basic component of their mainlines. A - 15-fathom section used in making up mainlines. B - 13-hook basket (unit) designed for albacore fishing. C - 11-hook basket used in fishing for larger tunas, such as yellowfin and big-eyed tuna. D - 6-hook "Standard" basket used in most of POFI's experimental fishing.

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The original POFI tuna long-line gear was derived from designs employed by Japanese and Hawaiian fishermen. A general discussion of the history, fabrication, and operation of such gear is included in reports by Shapiro (1950), June (1950), Murphy and Shomura (1953), and Niska (1953). So many changes have been made in the design of the gear since 1953 that a new account is necessary to acquaint the fishing industry with the successful innovations. It should be noted that the dimensions and basic design of the gear have not been changed; however, several modifications have increased the speed of setting and hauling and have resulted in greater flexibility. Each of these changes has been tested in the field under controlled conditions. The results of these field tests are discussed in Murphy and Shomura (1953), and Shomura and Murphy.1/

GENERAL DESCRIPTION

The basic unit of the long line is the "basket" or "skate" (fig. 1), a 210-fathom length of mainline with droppers and buoyline, stored in a canvas skid or a bamboo basket. In the POFI experimental fishing operations about 60 such baskets are joined together to make a day's set. Since they are identical in design, plans of only one basket are shown in the diagram.

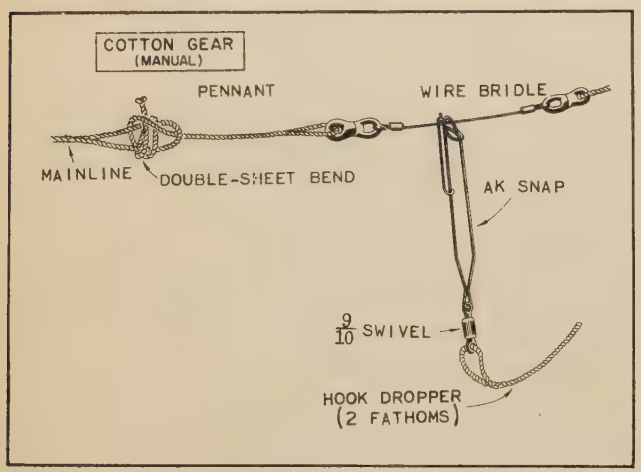

Fig. 2 - Method of joining two mainline sections, and details of wire bridle and branch-line attachment.

MAINLINE: The mainline of each basket is made up of 14 similar sections, each consisting of a 15-fathom length of cotton line with wire bridle and a short pennant or "pigtail" (fig. 1A). These sections are knotted together using the double sheet bend shown in figure 2. The principal advantage of such a system is that, since each section bears a one-hook dropper, various numbers of hooks from 1 to 13 per basket can be fished without resplicing or reworking the mainline. Another advantage of joining the sections with knots is that tangled sections of mainline may be removed without delay and set aside as the gear comes aboard.

DROPPER ATTACHMENT: Each basic mainline section has a swiveled wire bridle for the attachment of droppers (fig. 2). This fitting has eliminated one of the most troublesome defects of the old gear. Formerly, mainline sections were made up with eyesplices at each end and were joined by knotting the loops together; droppers were attached by clipping an AK snap into one eyesplice. When the gear was hauled, the incoming mainline rotated because of the twist developed by the lay of the line and droppers were wound around it. The resulting tangles seriously delayed recovery of the gear.

The wire-bridle system has virtually eliminated this type of tangling. Droppers are now joined to the mainline by clipping the AK snap over the wire bridle. Since there is ample clearance between wire and snap, the mainline can rotate freely without affecting the dropper. The swivels at the ends of the bridle also help to reduce the twisting effect caused by the lay of the line.

HOOK DROPPERS: The 10-fathom and 5-fathom hook droppers, or branch lines (gangions), have been cut to 3 fathoms (over-all length, including leader) and the

1/ Long-line fishing for deep-swimming tunas in the central Pacific, 1953. U. S. Fish and Wildlife Service, Spec. Sci. Rep.: Fish. No. 157.

costly sekiyama[2/] has been eliminated as unnecessary. The 3-fathom length marks the shortest length that can be efficiently fished; 2-fathom droppers have been tried but proved harder to coil and were more hazardous in setting and hauling than the 3-fathom type. Construction of droppers is shown in figures 2 and 3.

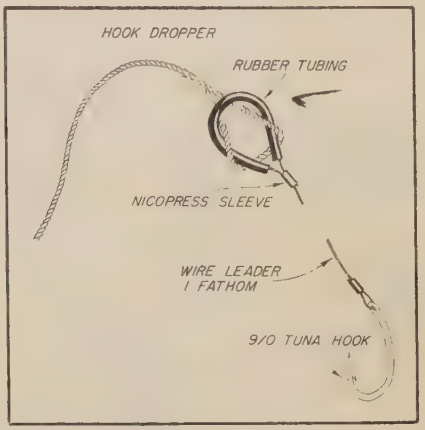

Fig. 3 - Details of branch line, leader, and hook assembly.

FLOATLINES: Floatlines, which join buoys and mainline, are made up of 5-fathom sections. The sections have an eyesplice at one end so that they may be joined by a double sheet bend. The depth of the mainline is varied by adding or removing sections without cutting or splicing line. Floatlines are joined to the mainline by the AK snap and knot shown in figure 4. Attempts have been made to use a wire bridle similar to the one used for the attachment for hook droppers, but the snaps opened up and this arrangement was discarded.

BUOY LIGHTS: Hauling operations may sometimes last until after dark, so battery-powered buoy lights are usually attached to the end poles and to several intermediate poles of the set. A typical light installation is shown in figure 5.

LONG-LINE CONTAINER: POFI long-line gear was originally stored in the standard bamboo basket commonly used in the Hawaiian and Japanese fisheries. This method of stowage was objectionable because of the space taken up by the empty baskets. POFI now stores gear in canvas skids similar to those used in the halibut long-line fishery (fig. 6).

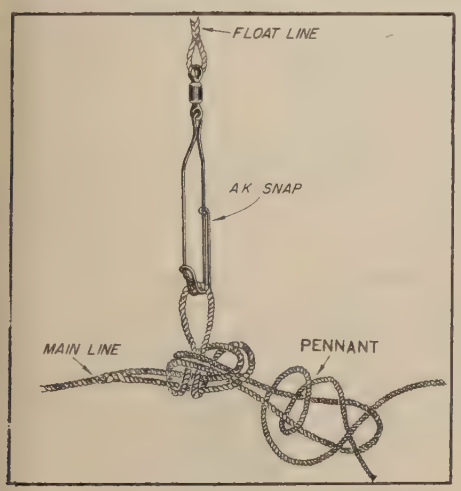

Fig. 4 - Attachment of floatline to mainline at juncture of two skates.

FABRICATION OF THE GEAR

PREPARATION OF LINE: Mainline, floatlines, and hook droppers are made of best grade hard-laid 261-thread cotton twine. Since the gear remains wet for long periods at sea, the line must be treated with some type of preservative. A commercial copper-base preservative is commonly used by POFI. Skeins of new line are cold-dipped for a period of three minutes in a full-strength solution and are then dried in the shade.

The treated line is then stretched and cut into 15-fathom lengths. To save time, several lines are cut simultaneously in the following fashion: skeins are opened out and placed on vertical reels; the ends of several lines are attached by brass swivels to the rear bumper of a jeep so that the lines can rotate freely to remove kinks; the lines are then unreeled and stretched out over a measured 15-fathom distance and a steady strain of 125 pounds is exerted until kinks are eliminated. A Dillion dynamometer is used to check tension on the lines and prevent overstretching.

MAINLINE: Cut lines are coiled down in sets of 14 pieces each, the number required to make up one skate. These basic mainline sections are then completed by splicing in eyes, wire bridles, and pennants as shown in the diagram (fig. 1A). The end pennant of each basket is made from $\frac{1}{4}$-inch cotton rope rather than 261-thread line and the end eyesplice is lengthened.

2/ Sekiyama or shanawa--a stiff pennant consisting of a linen or wire core served with cotton twine, used by Japanese and Hawaiian fishermen to connect the wire leader to the cotton branch line, and formerly employed in POFI long-lines.

Wire bridles 6 inches long are fashioned from $\frac{5}{64}$-inch 1 x 7 stainless wire rope. No. 2 Seadog swivels are fastened to the wire by means of Nicopress fittings (fig. 2).

HOOK DROPPERS: The construction of hook droppers is shown in figures 2 and 3. Two-fathom lengths of treated 261-thread line are made up with a special snap at the upper end. This snap, a model used by the Northwest trolling boats, is a No. 9/0 Kolstrand AK snap, but is constructed of heavy No. 7 wire and has a jaw opening of $\frac{1}{8}$-inch diameter. It is important that the AK snap be designed to fit the wire bridle with a small clearance, since otherwise the snap is apt to jam against the swivel. The lower end of the dropper terminates in an eyesplice to which is joined hook and leader, as shown in figure 3.

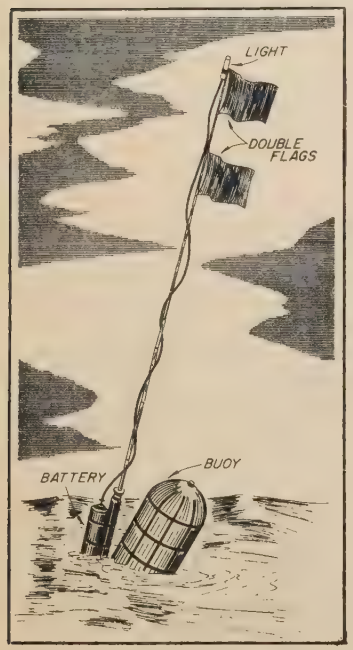

Fig. 5 - Battery-powered light buoy.

The leaders are fashioned of 6-foot lengths of .066-inch diameter right lay 1 x 7 galvanized plow-steel wire. Galvanized wire is used rather than stainless steel since it reduces the electrolytic action between hook and leader. Stainless steel leaders destroy hook plating in a very short time. A 3-inch loop in the end of the leader is fitted with a section of $\frac{3}{8}$-inch O.D. x $\frac{1}{8}$-inch I.D. industrial rubber tubing, which serves to prevent chafe. A 9/0 or 8/0 tuna hook is attached to the leader by a 1-inch loop fastened with a Nicopress sleeve (fig. 3). It should be noted that the hook is of a special shape, with a bent shank which allows the bait to hang in line with the leader. Such a hook has better fish-holding qualities than the conventional straight-shanked models.

FLOATLINES: Floatlines are made from 5-fathom lengths of 261-thread line. An AK snap is spliced into one end and an eye formed in the other. Mainline and floatlines are joined as shown in figure 4.

FLOATS: Floats used in the Hawaiian fishing industry include glass balls, wood billets, and metal tanks of various sizes. The floats used by POFI are made from surplus stainless-steel oxygen tanks of 2,100 cubic inches internal volume (figs. 7 and 8). These are fitted with a $\frac{3}{8}$-inch galvanized eye bolt for attachment of a floatline. Since the tank comes provided with a $\frac{1}{4}$-inch outlet, it is necessary to reduce this opening by fitting a $\frac{1}{8}$-inch to $\frac{1}{4}$-inch hex-head pipe bushing between tank and bolt. An 8-inch grommet of $\frac{3}{8}$-inch diameter manila rope is spliced into the eye for attachment of the bamboo pole. A $\frac{3}{8}$-inch stainless-steel thimble protects the grommet against chafe (fig. 8). Buoys are painted a bright orange for greater visibility.

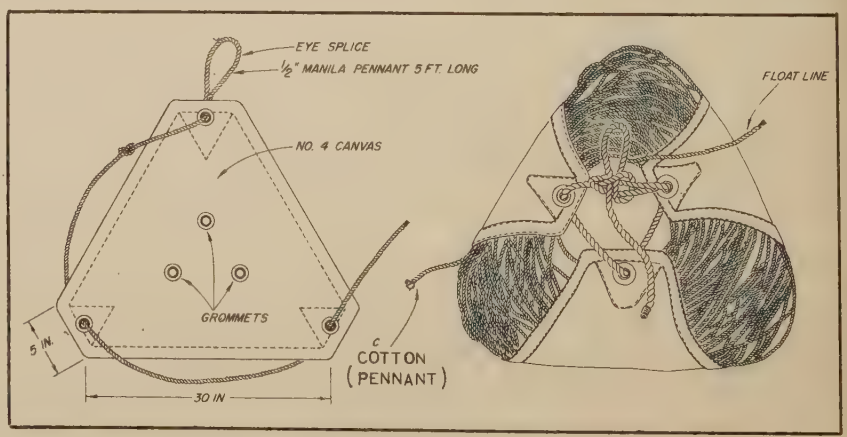

Fig. 6 - Canvas skid for stowing long-line skates.

FLAGPOLES: Alternate buoys have poles with flags to serve as markers in locating gear (fig. 7). Poles are select bamboo 14 to 16 feet in length with a butt diameter of $1\frac{1}{4}$ inches to $1\frac{1}{2}$ inches and a tip diameter of about $\frac{5}{8}$-inch.

The poles are protected from chafing on the floats by a 15-inch section of heavy air hose. Split lengths of hose are clamped on the pole with a lower end 6 feet 6 inches from the butt. Clamps are $\frac{3}{8}$-inch Band-It straps secured with the buckles fixed over the cut. This attachment is made so that the buckles are turned away from the buoy, presenting only the smooth band to minimize chafing.

A 5-inch loop of $\frac{3}{8}$-inch manila line is fastened at the bottom of the pole for attaching the floatline. This loop is held in place as follows: a rosette is made in each end of the line and a Band-It strap is clamped midway on the rosette, which serves as a cushion preventing the loop from slipping under the band. The ridge at the lower joint of the pole tends to prevent the loop and band from slipping off the butt of the flagpole.

The float is tied to the flagpole by a 4-foot lanyard of $\frac{3}{8}$-inch manila line, which is secured to the flagpole just below the chafing gear. The end of the lanyard next to the pole ends in an eyesplice, as shown in figure 8. A safety line of 261-thread cotton line runs from this eye to the bottom of the pole, where it is made fast to the manila loop. If the bamboo pole breaks during fishing operations, the safety line prevents loss of buoy and floatline. On setting the gear, the free end of the lanyard is joined to the grommet of the float by a reverse sheet bend with bow (fig. 8).

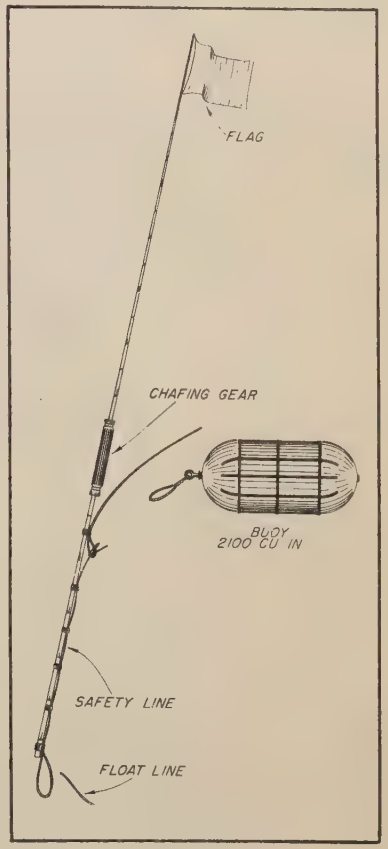

Fig. 7 - Complete flag and float assembly, showing chafing gear.

Bunting flags are attached to the top of the flagpoles by waxed, doubled, cotton-thread ties fixed to the corners of the flags. POFI flags are dyed a bright orange since this color seems to show up well under all sea conditions. The size of flags has been increased to $1\frac{1}{2}$ square feet in an effort to increase the range of visibility. Double flags are used to mark various portions of the set such as the ends and center.

CANVAS SKID: To make the skid (fig. 6), No. 4 canvas duck is cut in the shape of an equilateral triangle 45 inches on a side. Corners are turned in with No. 5 grommets punched in the center. A $\frac{3}{8}$-inch manila becket, 60 inches long, is laced through the grommets. A 3-inch loop is spliced on one end, and the standing end is securely whipped. The loop is secured on one grommet by an overhand knot immediately behind the eyesplice. With the line in place the standing end is laced through the other two grommets and passed through the eye to form a bight. A slip knot finally secures the line. Skids have brass grommets in the bottom to provide proper drainage and ventilation of wet line.

ASSEMBLING LINES FOR SETTING

Prior to setting, mainline and branch lines are assembled and the gear is carefully coiled down on the skid. The bottom end pennant is left exposed for joining to

the next basket (fig. 6). Hook-dropper coils are made up smaller than mainline coils and are secured by hooking the tuna hook into the rubber chafing gear on the wire leader. The floatline is coiled down on top of the pile, the skid is then tied up and the gear is ready for setting.

SETTING

The gear is laid in a straight line and in a direction relative to the wind and sea which will make it easy to haul the line. Hauling is easiest when the wind blows from about 30° off the bow on the side of the line hauler. Therefore, gear is usually laid with the wind about 30° off the stern opposite from the line hauler. When course is reversed to pick up the gear, if no wind shift has occurred, the winch side will be the weather side and wind and sea will be broad on the bow.

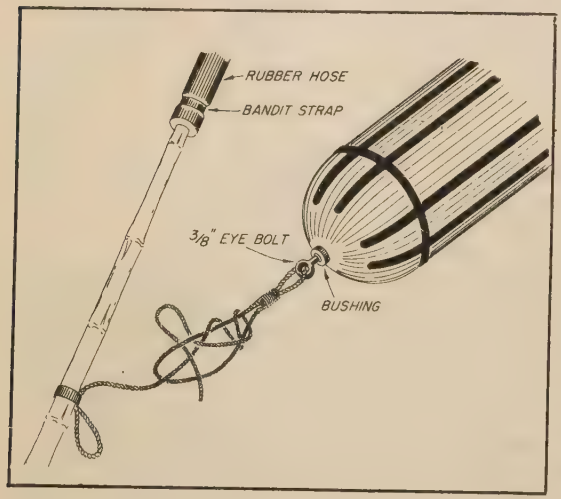

Fig. 8 - Details of attachment of float to flagpole.

When setting close to islands or banks or in an area where currents are known to be strong, the direction of set must be chosen with care. Setting across a current boundary is avoided as the mainline is apt to part with the strain. Particular care must be taken in setting in shoal water close to land where strong surface currents may sweep the gear into shallow water before it can be recovered.

Setting is usually done from a "setting table" on the stern of the vessel. This is a wooden bench large enough to hold several skates of gear and the bait needed for the set. In setting (1) the vessel is put on the desired course; (2) floatline, buoy, and flagpole (usually with double flag) are joined to the first basket and pitched overboard; (3) one fisherman pays out coils of mainline while others uncoil droppers and bait hooks.

The amount of slack in the mainline, and consequently the fishing depth of the gear, is controlled by the fisherman throwing out the mainline coils. These may be thrown out rapidly to give a "slack set" which fishes at a comparatively great depth, or they may be held until the line is stretched out taut by the vessel, which results in a comparatively shallow fishing depth. A slack set may also be accomplished by steering a zigzag course while paying out the line.

HAULING

LONG-LINE HAULER: The gear is hauled with a Japanese line hauler of the type shown in figure 9. Such a winch is used in preference to an ordinary gurdy because it coils down the mainline automatically with little attention from the winch operator.

The coiling of the line is accomplished by the hauling head shown at the top of the winch. This assembly consists of a split sheave (A) grooved to fit the diameter of the line to be hauled; a wide center wheel with replaceable rubber collar (B); and a movable brass idler (C) controlled by the lever at the left. All three units are connected by a gear train which synchronizes them when they are turned by the drive shaft in the base of the winch.

In hauling, the incoming line is led under the grooved sheave, then over the center wheel and between it and the brass idler. The grooved sheave grips the line

and the idler squeezes it against the rubber collar giving friction to pull the line in as the sheaves rotate.

The line is deflected downward by the brass plate (D) to a platform below, where it coils itself. The size of the coil is dependent upon the distance between plate and platform, so it is necessary to adjust the height of the latter with care.

The hauling head is turned by the drive shaft at the bottom of the winch through a multiplate oil-bathed disc clutch located in the base of the winch. The foot-operated clutch control is mounted near the ship's bulwark close to the overside roller so that the winch operator can see the incoming branch lines easily. The clutch control is so arranged that the winch operates continuously unless the clutch pedal is depressed.

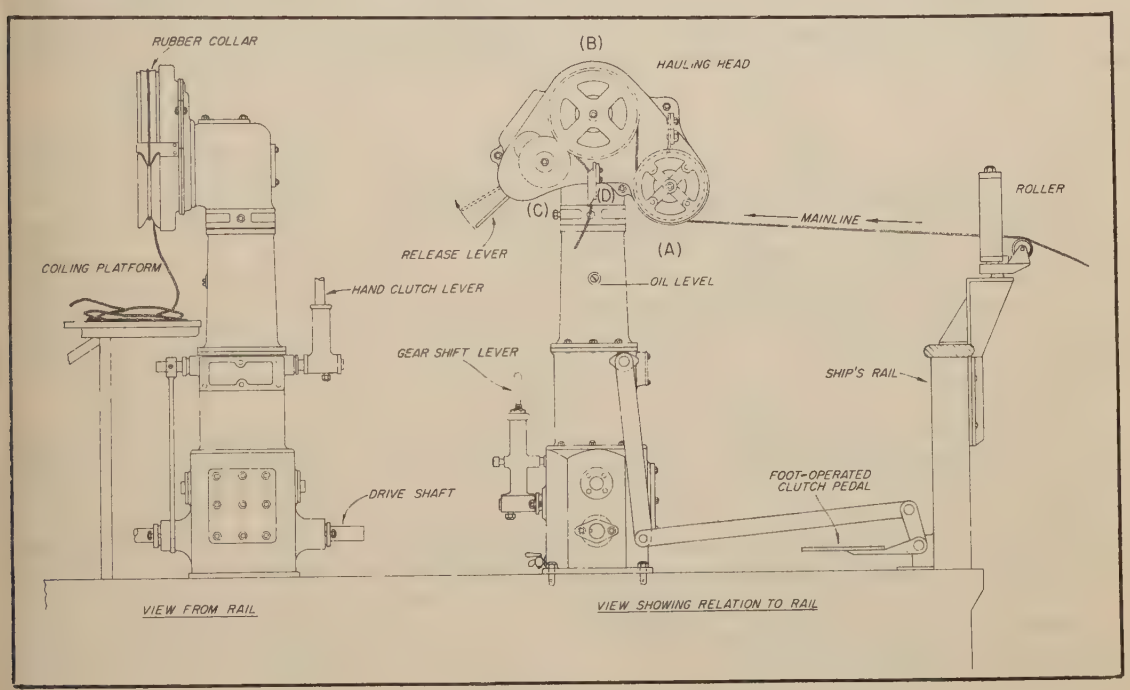

Fig. 9 - Japanese long-line hauler.

The gear-shift lever shown at the lower left controls the hauling speed. With a drive shaft input speed of 300 r.p.m., high gear yields a line speed of about 1,000 ft./min., low gear a speed of 500 ft./min.

Hawaiian and Japanese fishing vessels frequently drive line haulers with a line shaft take-off from the main engine. On POFI vessels an electric drive (3 hp. waterproof motor d.c. 1,725 r.p.m.) and a 5:1 gear reduction, or a hydraulic drive (7.5 hp. 35.8 gal./min. pump at 1,200 r.p.m.) are used to power haulers.

HAULING PROCEDURE: Hauling operations on Japanese vessels have been described by Shapiro (1950) and Shimada (1951). On POFI vessels the mainline is brought aboard, led through the overside rollers, and fed into the line hauler. The winch is controlled by the clutch operator, who stands at the rail and stops the winch by the foot control to detach branch lines. The fisherman tending and coiling line can also stop the hauling by pulling back on the idler lever, thus releasing tension on the line. Floatlines and hook droppers are detached as they reach the overside roller. The buoys and flagpoles are untied and stowed, and the floatlines and droppers are coiled by hand. As the mainline coils under the line hauler, floatlines and

droppers previously coiled by hand are reattached in the proper places so that the "basket" is ready for use the following day.

If the gear is not to be used for some time, as for example, when the vessel changes fishing grounds, droppers are removed from the mainline and are stowed separately. If practicable, hooks and leaders are removed from the droppers, for if assembled gear is stored wet for long periods, metallic components react with the damp line to cause weak spots. Gear is dried whenever possible, but exposure to direct sunlight is avoided.

MATERIALS USED TO MAKE UP GEAR

The following list of materials contains the items necessary to make up one basket of POFI 11-hook long-line gear. Prices of gear have been derived from Government bid quotations on material delivered in Honolulu and, because of fluctuations in market prices and shipping costs, are only estimates of cost to others.

Item	Quantity Required	Cost ($)
1. Mainline Section:		
Wire, stainless steel $\frac{5}{64}$" diameter 1 x 7, right lay	6 in.	0.03
Sleeves, Nicopress copper, $\frac{1}{16}$", 18-1-C	2 ea.	0.08
Swivels, brass, Seadog No. 2, trolling	2 ea.	0.46
Twine, cotton, 261-thread, treated	15 fathoms	1.25
Pennant, 261-thread twine, treated	24 in.	0.03
Total per unit		1.85
2. Floatline:		
Snap, AK, No. 9/0 design but made from 7/0 wire, brass barrel swivel	1 ea.	0.35
Twine, cotton 261-thread	10 fathoms	0.90
Total per unit		1.25
3. Float Assembly:		
Tank, surplus, stainless steel oxygen, 2,100 cu. in.	1 ea.	10.40
Eyebolt, $\frac{3}{8}$" x $4\frac{1}{2}$", galvanized	1 ea.	0.55
Bushing, pipe, $\frac{1}{4}$" - $\frac{1}{8}$", galvanized	1 ea.	0.16
Thimble, wire rope, $\frac{3}{8}$", galvanized	1 ea.	0.10
Manila rope, $\frac{3}{8}$" diameter	24 in.	0.05
Sealing compound, lashing twine	-	0.10
Paint, Westinghouse, orange enamel	$\frac{1}{2}$ pt.	0.40
Total per unit		11.76
4. Bamboo Pole Assembly:		
Pole, bamboo, 14" long x $1\frac{1}{2}$" at base	1 ea.	0.70
Flag, bunting, 14" x 18", orange	1 ea.	0.24
Hose, air, surplus, heavy	14 in.	0.80
Strapping, Band-It, $\frac{3}{8}$" width	18 in.	0.09
Buckles, Band-It, $\frac{3}{8}$" width	3 ea.	0.18
Rope, Manila, $\frac{3}{8}$" diameter	6 ft.	0.15
Total per unit		2.16
5. Hook Dropper:		
Snap, AK, 9/0 formed of 7/0 wire with brass barrel swivel	1 ea.	0.35
Twine, cotton, 261-thread	12 ft.	0.18
Tubing, rubber, black industrial, $\frac{3}{8}$" O.D. x $\frac{1}{8}$" I.D.	6 in.	0.08
Sleeves, Nicopress, $\frac{1}{16}$"	2 ea.	0.08
Wire rope, leader, .066" dia. 1 x 7 right lay plow steel, galvanized	6 ft.	0.06
Hook, 9/0 or 8/0 mustad flatted tinned, tuna	1 ea.	0.18
Total per unit		0.93

Item	Quantity Required	Cost ($)
6. Skid:		
Canvas, No. 4, triangle 45" each side	1 ea.	1.03
Manila rope, $\frac{1}{2}$" diameter	60 in.	0.20
Spur grommet, heavy, brass	6 ea.	0.12
Total per unit		1.35

Since POFI gear can be assembled so as to fish different numbers of hook droppers, the cost of individual baskets varies according to the type of gear used. Costs of typical gear assemblies are shown below:

Components	6-Hook "Standard"	11-Hook Tuna	13-Hook Albacore
Mainline--14 sections basket	$25.90	$25.90	$25.90
Floatline	1.25	1.25	1.25
Buoy	11.76	11.76	11.76
Bamboo pole 1/	2.16	2.16	2.16
Droppers	5.58	10.23	12.09
Canvas skid	1.35	1.35	1.35
Total Skate	$48.00	$52.65	$54.51

1/ Bamboo poles are usually attached to alternate buoys only.

DISCUSSION

The greatest defect of the present gear is the relatively short life of the cotton twine used for mainline and droppers. Three factors combine to cause this relatively rapid deterioration.

First, due to conditions inherent in the fishery, the line is often overstrained. This method of fishing is necessarily nonselective as far as catch is concerned, and large sharks and marlins often take the hooks. Heavy fish chafe the line and sometimes stretch gear beyond its elastic limit. Overstraining of the line also occurs during fishing operations in rough weather, for it is then difficult to keep the vessel close up to the gear. As the vessel drifts away from the set, the mainline is sometimes parted before the ship can recover position.

A second factor is wear and tear on the line during hauling operations. Some abrasion is due to chafing of hooked fish when droppers tangle with the mainline, but most of the damage is done by wear on the line as it passes over the rollers and through the line hauler. Wear is especially evident where swivels are inserted in the line.

Finally, the line deteriorates because proper care of the gear is extremely difficult. While on the fishing grounds, gear is set during the day and stored damp at night in the skids; it is frequently stored damp for several days at a time while the vessel changes fishing grounds. Under such conditions cotton line loses strength rapidly. It has been possible to make some progress in methods of preserving gear. For instance, POFI gear treated with copper-naphthenate preservatives now lasts about twice as long as the tan bark-treated line used in the Hawaiian fishery. Tarred line used exclusively by the industry in Japan and to some extent in Hawaii is now being tested but has not yet been evaluated.

It should be pointed out that the gear described in this report has not been designed primarily for commercial use. Rather, an effort has been made to develop a type of gear which would be extremely flexible and which could be changed rapidly for various types of experimental fishing. During the evolution of this gear, several design limits appear to have been reached. Thirteen hooks per basket appear to be the maximum number practicable with this type of gear. As many as 21 hooks per

basket have been fished, but the net result was a slowing down and a reduction of efficiency in both setting and recovery of the gear. Hook droppers also have been shortened to their minimum length. Thus, it is anticipated that the general design of the gear may remain unchanged for some time but that futher improvements may well be made in the speed with which the gear is operated and the durability of the materials from which it is constructed.

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MID-PACIFIC OCEANOGRAPHY
Part VI, Hawaiian Offshore Waters, December 1949-November 1951

SPECIAL SCIENTIFIC REPORT–FISHERIES No. 152

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Explanatory Note

The series embodies results of investigations, usually of restricte scope, intended to aid or direct management or utilization practices an as guides for administrative or legislative action. It is issued in limite quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

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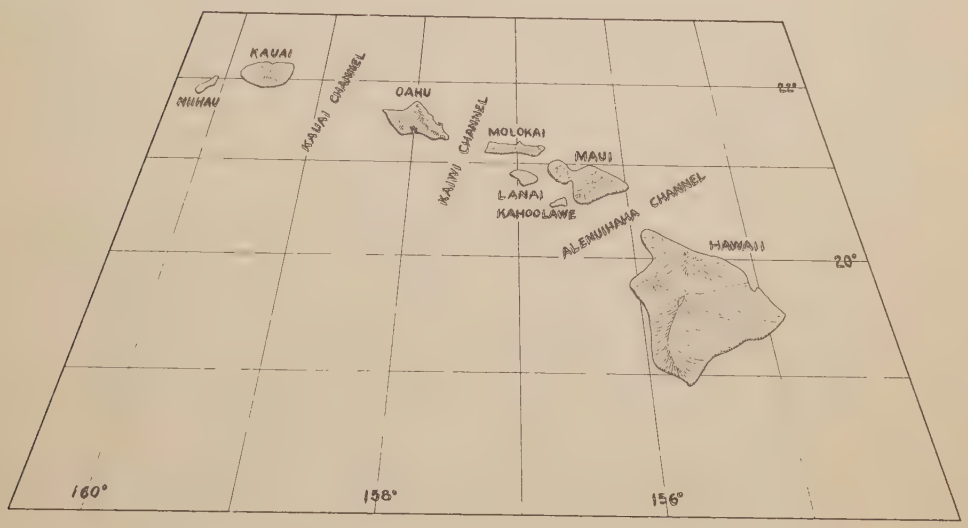

MID-PACIFIC OCEANOGRAPHY, PART VI

HAWAIIAN OFFSHORE WATERS

DECEMBER 1949-NOVEMBER 1951

By

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Pacific Oceanic Fishery Investigations
Honolulu, T. H.

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This is the sixth of a series of descriptive reports on mid-Pacific oceanography by the Pacific Oceanic Fishery Investigations. The previous oceanographic reports presented and discussed data collected in the equatorial waters of the mid-Pacific.1/ The present report covers the data collected during the first three of a series of six general oceanographic cruises of the research vessel Hugh M. Smith in the waters adjacent to the Hawaiian Islands. The periods covered by the oceanographic phases of the cruises were: cruise 1, December 13-21, 1949; cruise 10, July 19-31, 1951; and cruise 12, October 23 to November 2, 1951.

The surveys of Hawaiian waters were initiated on the premise that the abundance and movements of the skipjack, Katsuwonus pelamis (Linnaeus), which forms the basis for the principal fishery of the islands, are controlled by events in the sea (Sette et al. 1954). The skipjack catches of the local fleet were used as a guide in planning the geographical and seasonal coverage of cruises 10 and 12. Cruise 10 was made when the fishery was at the summer peak, and cruise 12 was made during the middle of the fall decline.

The observational programs of these cruises were designed to collect chemical, physical, and biological data which could be used to map the circulation pattern of the island waters. From the circulation pattern it was hoped to locate areas where enough vertical motion might occur to enrich the surface layers and increase biological activity. On each cruise observations of temperature and salinity suitable for computation of currents in the upper 1,000 m. were made as well as bathythermograph lowerings for details of the temperature structure in the upper 900 ft. (270 m.). Other observations varied from cruise to cruise. Analyses for dissolved oxygen, which together with determinations of temperature and salinity help in tracing the circulation of different water masses and in their discussion, were made on cruises 1 and 10. Observations of inorganic phosphate, which is useful as an indicator of areas where turbulence and upwelling are sufficient to carry nutrients from the deep water to the euphotic zone, were made on cruise 12. Collections of zooplankton, which serves to indicate areas of past enrichment, were made on cruises 10 and 12. A geomagnetic electrokinetograph (GEK) was used to make current measurements during cruise 12.

Since the primary purpose of this report is to present the processed data in a form that is usable to POFI biologists and others interested in the hydrography of the area, the discussion of the results is purely descriptive. The major features of the circulation pattern and the results of the various observations2/ are described separately for each cruise. In the final discussion the features recurrent from cruise to cruise are explained in terms of the effect the island chain has on the general oceanic circulation in the area. These features are then examined further for areas in which enrichment of the euphotic zone might occur.

PROCEDURES

The vessel equipment, sampling methods, and most of the procedures used in processing the basic data have been described in the earlier reports by Cromwell (1951 and 1954), Austin (1954), and Stroup (1954). Minor changes which were made in the construction of cross sections, and procedures used in the construction of lateral (on sigma-t surfaces) and horizontal plots and in preparing types of data not used in the previous reports are described below.

A slightly different procedure was used in the preparation of the salinity, dissolved oxygen, and inorganic phosphate profiles. In the previous reports, which were concerned primarily with meridional aspects, the principle of drawing

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1/ Mid-Pacific Oceanography, Transequatorial Waters, Part I, Cromwell (1952); Part II, Cromwell (1954); Part III, Austin (1954); Part IV, Stroup (1954); Part V, Austin (1954).

2/ Except for zooplankton, which was the subject of a separate report by King and Hida (1954).

sections so that there was consistency among the various fields was maintained as rigidly as possible (Montgomery 1954). The station plots of each variable were drawn against temperature and their final shapes were determined by comparing them with the curves of the adjoining stations in the sections (Stroup 1954). In constructing the profiles the isopleth intervals were read from these plots, but their final shape was determined by placing the profiles over the sigma-t surfaces and then, with careful consideration of observed values, fairing them in as nearly parallel to the sigma-t isopleths as practicable. In this report, however, all surrounding stations were considered in constructing each of the station curves, so greater consideration was given to the interpolated isopleth intervals.

The values used in constructing the horizontal and lateral plots of dynamic topography, temperature, salinity, and sigma-t were interpolated from the individual station plots. Whenever it was possible, the spacing of the isolines on these plots was determined from the cross sections.

The topography of the sigma-t surfaces was drawn on the assumption that the major components of the subsurface flow are isentropic (along surfaces of equal potential density). The topography of four surfaces is shown for each cruise. The lowest valued surface varied from cruise to cruise and in each case was selected to depict the conditions at the lower limit of the quasi-homogeneous surface layer. The 24.0, 25.0, and 26.0 surfaces were selected as standard intervals to show the changes in topography and conditions between the surface and the intermediate water. When the variance of the salinity on these surfaces was great enough to be of value in tracing the circulation, the salinity contours were superimposed.

Instead of using the dynamic height[3] cross sections to compute velocities normal to the sections, as was done along the meridional sections described in the previous reports, dynamic height cross sections were used to construct plots of the geopotential topography[4] for the 0-, 50-, 100-, 200-, and 300-decibar surfaces. The spacing of the contours indicates the velocity relative to the 1,000-decibar surface.

Only a single geostrophic velocity scale is shown for each of the horizontal plots of geopotential topography. The velocities were computed for 20°N. latitude using the tables and formula given in H. O. 614 (LaFond 1951). This, taking into consideration the latitudinal difference, results in an apparent error of +12 percent at the northern limits of the area (23°N.) and of -10 percent at the southern limit (18°N.). Considered alone, these appear to be errors of significant magnitude, however, if the indeterminable errors in direction and magnitude that could be caused by internal waves and topographical complications are also considered, the mean velocity diagrams become more acceptable. Seiwell (1937) found that internal waves would cause fluctuations in dynamic height of 14 cm. per day. Defant (1950) found that apparent eddies appeared in the data for the coastal waters of California if allowances were not made for internal waves. In the waters treated in this study the proximity to land and the bottom topography would also cause deviation of the actual currents from those indicated by the dynamic topography (Parr 1936).

In order to provide a general picture of the expected incident winds and currents for the cruise periods, monthly summaries of ships' reports of observed winds and currents have been prepared for the area east of (upstream from) the

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3/ The dynamic height is used in oceanography to express the vertical distance in gravitational potential between points in a selected isobaric (pressure) surface and a reference surface where the pressure field and the gravitational field are assumed to coincide. It is usually expressed in dynamic meters, which represents the work performed when a unit mass is lifted approximately 1 m. (.98 m. at sea level) against the force of gravity.

4/ The geopotential (dynamic) topography of the isobaric surfaces is simply a plot of the contours of equal dynamic height. The contours represent the lines along which a body can be moved without work being performed against the force of gravity.

Hawaiian Islands. The wind data (table 1) were based on the U. S. Navy Hydrographic Office Pilot Charts (H. O. 1401) and give the mean force and the percentage of the ships' wind observations that were reported for each cardinal and intercardinal point. The percentages were computed by averaging the values for the 5° squares between 15°N. and 25°N. latitude at 150°W. to 155°W. longitude.

Table 1.--Average force (Beaufort) of the wind and percentage of ship's observations reported from each of the cardinal and intercardinal points of the compass in the area east of the Hawaiian Islands. (H. O. 1401)

Direction	January		February		March		April		May	
	Ave. force	Per-cent	Ave. force	Per-cent	Ave. force	Per-cent	Ave. force	Per-cent	Ave. force	Per-cent
N	3-4	5	4	4	4	5	4-5	6	3	3
NE	4	29	4	40	4	40	4	46	4	52
E	3-4	42	3-4	34	4	28	4	35	3-4	34
SE	3	8	3	9	2-3	9	3	6	3	4
S	3	4	3	6	3	8	-	< 2	3	2
SW	3	2	3	3	4	4	-	< 2	-	< 2
W	4	4	4	2	4-5	3	-	< 2	-	< 2
NW	4	4	3	2	3	3	-	< 2	3	2
Calm	-	2	-	<2	-	< 2	-	< 2	-	< 2

Direction	June		July		August		September		October	
	Ave. force	Per-cent	Ave. force	Per-cent	Ave. force	Per-cent	Ave. force	Per-cent	Ave. force	Per-cent
N	-	<2	3	2	4	4	3	2	4	3
NE	4	54	4	64	4	56	3-4	56	4	47
E	3	37	3	30	3	34	3-4	33	3-4	38
SE	3	4	3	2	3-4	5	3	3	4	6
S	-	<2	-	<2	-	<2	-	<2	3	2
SW	-	<2	-	<2	-	<2	-	<2	-	<2
W	-	<2	-	<2	-	<2	-	<2	-	<2
NW	-	<2	-	<2	-	<2	-	<2	-	<2
Calm	-	<2	-	<2	-	<2	-	<2	-	<2

Direction	November		December		Annual average percent
	Ave. force	Per-cent	Ave. force	Per-cent	
N	4	5	4-5	6	4
NE	4	47	4	40	48
E	3-4	29	3-4	30	34
SE	3	10	4	10	6
S	3	3	3	6	3
SW	3-4	2	2-3	2	< 2
W	2	2	-	<2	< 2
NW	-	<2	3	3	< 2
Calm	-	<2	-	<2	< 2

The monthly current data (table 2) were computed from the U. S. Navy Hydrographic Office Current Atlas of the Northeastern Pacific (H. O. 570) in the same manner as the monthly wind data. The velocities are given in increments of 0.33 knots, which probably represents the limit of accuracy of the ships' observations on which they are based. At the foot of each monthly column is a mean direction for the month which has been taken from the current arrows given on the Pilot Charts (H. O. 1401).

Table 2.--Average velocity of the drift and the percentage of ship's observation reported towards each of the cardinal and intercardinal points of the compass in the area east of the Hawaiian Islands computed from data given in the Atlas of Surface Currents of the Northeastern Pacific (H. O. 570). Average drift was taken from H. O. 1401

Direction	January		February		March		April	
	Average velocity	Percent	Average velocity	Percent	Average velocity	Percent	Average velocity	Percent
N	0.34-0.66	10	0.34-0.66	11	0.34-0.66	13	0.00-0.66	11
NE	0.00-0.66	8	0.34-0.66	11	0.00-0.66	8	0.00-0.66	8
E	0.34-0.66	6	0.34-0.66	5	-	< 5	-	< 5
SE	0.00-0.66	7	0.34-0.66	7	-	< 5	-	< 5
S	-	< 5	0.00-0.99	9	-	< 5	0.00-0.66	9
SW	0.34-0.66	12	0.00-0.66	18	0.34-0.66	15	0.34-0.66	8
W	0.34-0.66	28	0.34-0.66	21	0.34-0.66	33	0.34-0.66	38
NW	0.34-0.66	18	0.34-0.99	15	0.34-0.66	15	0.34-0.66	17
Nil	-		-	< 5	-	6	-	< 5
Ave. °T	310		305		300		300	

Direction	May		June		July		August	
	Average velocity	Percent	Average velocity	Percent	Average velocity	Percent	Average velocity	Percent
N	-	< 5	0.00-0.66	13	0.34-0.66	10	0.34-0.66	12
NE	0.34-0.66	5	0.34-0.66	9	0.34-0.66	5	-	< 5
E	-	< 5	-	< 5	-	< 5	-	< 5
SE	-	< 5	-	< 5	-	< 5	-	< 5
S	-	< 5	-	< 5	-	< 5	-	< 5
SW	0.34-0.66	17	0.34-0.66	13	0.34-0.66	10	0.34-0.66	14
W	0.34-0.66	44	0.34-0.66	35	0.34-0.66	38	0.34-0.66	32
NW	0.34-0.99	13	0.34-0.66	19	0.34-0.66	20	0.34-0.66	20
Nil	-	6	-	5	0.34-0.66	7	0.34-0.66	6
Ave. °T	280		295		295		295	

Direction	September		October		November		December		Annual average percent
	Average velocity	Percent	Average velocity	Percent	Average velocity	Percent	Average velocity	Percent	
N	0.34-0.66	11	0.34-0.66	10	0.00-0.66	10	0.00-0.66	7	10
NE	0.34-0.66	5	0.34-0.66	8	-	< 5	-	< 5	9
E	-	< 5	-	< 5	0.34-0.66	6	0.34-0.66	5	< 5
SE	-	< 5	0.00-0.33	8	-	< 5	-	< 5	< 5
S	-	< 5	-	< 5	-	< 5	-	< 5	< 5
SW	0.34-0.66	10	0.34-0.66	15	0.34-0.66	21	0.34-0.66	16	14
W	0.34-0.66	38	0.34-0.66	34	0.34-0.66	32	0.34-0.99	36	34
NW	0.34-0.66	20	0.34-0.66	19	0.34-0.66	12	0.00-0.66	18	17
Nil	0.34-0.66	6	-	6	0.34-0.66	9	-	6	6
Ave. °T	260		280		270		290		

To show the short-period fluctuations in the currents incident to the islands that could have been expected if the effect of the wind were assumed to be instantaneous, tables of daily wind and current (tables 3-5) were computed for the week preceding and for the period of the cruises. The choice of the 1-week period before the cruise was purely arbitrary, and the data are merely included as background. The winds were computed from the pressure gradients indicated by the U. S. Weather Bureau Synoptic Weather Maps and in turn were used to compute the currents.

A point at 20°N. latitude, 150°W. longitude was selected as a standard reference because the majority of the winds were easterly. Inspection of the charts indicated that one value per day is sufficient to reflect the major changes in the pressure pattern, so only the 1200Z charts were used.

Table 3.--Cruise 1, computed surface winds and currents at 20°N. and 155°W. Winds were computed from 1200Z, U. S. Weather Bureau Synoptic Charts by the method described in U. S. Navy Hydrographic Office Miscellaneous Publication 11,275. Currents were computed by Ekman's formulae

Date	Wind Dir. °T	Wind velocity kt.	Wind fetch miles	Current Dir. °T	Current velocity kt.	Remarks
12-7-49	090	14	1200	315	.3	
12-8-49	145	11	480	010	.2	Low centered at 23°N.-169°W.
12-9-49	120	15	390	345	.3	Low centered at 24°N.-164°W.
12-10-49	115	17	510	340	.4	Stationary front 20°N.-160°W. to 17°N.-165°W.
12-11-49	120	13	470	345	.3	
12-12-49	105	13	650	330	.3	
12-13-49	090	25	1450	315	.5	
12-14-49	075	20	750	300	.4	
12-15-49	120	11	560	345	.2	Low centered at 29°N.-164°W.
12-16-49	120	18	600	345	.4	Low centered at 29°N.-167°W.
12-17-49	120	15	500	345	.3	Shallow trough along 165°W.
12-18-49	110	9	900	335	.2	Shallow trough along 160°W.
12-19-49	110	9	600	335	.2	Low forming over the islands.
12-20-49	-	-	-	-	-	Trough over the islands
12-21-49	-	-	-	-	-	well developed trade winds east of the islands.

The wind velocities were obtained by first computing the geostrophic wind from the weather charts and then multiplying it by a reduction factor which took into account the curvature of the isobars (H. O. Misc. Pub. 11,275). Most of the time the islands were under the influence of the Eastern North Pacific High, and, as indicated by the large fetches, the isobars had little curvature, so 0.67, the value for isobars of small anti-cyclonic curvature, was used. During the periods when lows or troughs were over the islands 0.60, the factor for isobars of great cyclonic curvature, was used. Whenever possible, the reliability of these computed

values was checked by comparing them with ships' observations. With few exceptions the difference was not more than one force of the Beaufort scale or one compass point, which are considered satisfactory checks.

Table 4.--Cruise 10, computed surface winds and currents at 20°N., 155°W. Winds were computed from the 1200Z, U. S. Weather Bureau Synoptic Charts by the method described in the U. S. Hydrographic Office Miscellaneous Publication 11,275. Currents were computed by Ekman's formulae

Date	Wind Dir. °T	Wind velocity kt.	Wind fetch miles	Current Dir. °T	Current velocity kt.	Remarks
7-9-51	095	9	490	320	.2	
7-10-51	080	13	960	315	.3	
7-11-51	095	17	600	320	.4	
7-12-51	090	13	810	315	.3	
7-13-51	085	20	900	310	.4	
7-14-51	080	13	1150	305	.3	
7-15-51	110	10	1300	335	.2	
7-16-51	075	13	150	300	.3	Wave in isobars E. of the islands.
7-17-51	080	13	600	305	.3	
7-18-51	100	14	600	325	.3	
7-19-51	090	18	750	315	.4	
7-20-51	120	13	300	345	.3	Wave in isobars W. of the islands.
7-21-51	090	15	1150	315	.3	
7-22-51	105	17	1250	330	.4	
7-23-51	105	15	750	330	.3	
7-24-51	095	14	750	320	.3	
7-25-51	095	14	650	320	.3	
7-26-51	090	13	850	315	.3	
7-27-51	090	14	1250	315	.3	
7-28-51	080	13	1100	305	.3	
7-29-51	090	13	1100	315	.3	
7-30-51	105	10	600	330	.2	
7-31-51	100	13	550	325	.3	

Table 5.--Cruise 12, computed surface winds and currents at 20°N., 155°W. Winds were computed from the 1200Z U. S. Weather Bureau Synoptic Charts by the method described in the U. S. Hydrographic Office Miscellaneous Publication 11,275. Currents were computed by Ekman's formulae

Date	Wind Dir. °T	Wind velocity kt.	Wind fetch miles	Current Dir. °T	Current velocity kt.	Remarks
10-13-51	075	9	1050	300	.2	
10-14-51	090	11	800	315	.2	
10-15-51	095	14	600	320	.3	
10-16-51	125	10	500	350	.2	
10-17-51	115	10	500	340	.2	
10-18-51	120	11	450	345	.2	
10-19-51	100	14	500	325	.3	
10-20-51	100	14	800	325	.3	
10-21-51	090	11	750	315	.2	
10-22-51	070	14	650	295	.3	
10-23-51	080	14	750	305	.3	
10-24-51	095	13	1250	320	.3	
10-25-51	105	10	1100	330	.2	
10-26-51	120	11	500	345	.2	
10-27-51	130	8	600	355	.2	Low at 25°N.-157°W.
10-28-51	170	9	300	035	.2	Low at 26°N.-163°W.
10-29-51	150	13	500	015	.3	Low at 27°N.-161°W.
10-30-51	150	9	500	015	.2	Trough along 163°W.
10-31-51	-	-	-	-	-	Small trough over the Hawaiian Islands.
11-1-51	170	9	100	035	.2	Deep trough over the Hawaiian Islands. Front 30 miles north of Kauai.

The fetch was computed and included as an index to the extent of the wind field. It was the distance between 20°N., 150°W. and the point where the curvature of the isobars increased until they made an angle greater than 30° with their direction at 20°N., 150°W.

The wind direction was obtained by applying the rule that outside the tropics in the Northern Hemisphere the wind over the ocean deviates 80° to the right of the pressure gradient.

The ocean current velocities and directions were computed from the wind data using the empirical relationships derived by Ekman (Sverdrup et al. 1946, p. 494) and assuming that the wind forces acted instantaneously. The formula used to compute the velocities was

$$\frac{v}{W} = \frac{0.0127}{\sqrt{\sin \varphi}}$$

where v = current velocity, W = wind velocity, and φ = latitude. The direction was obtained by applying the rule that the current is directed 45° to the right of the wind in the Northern Hemisphere.

During cruise 12 surface or near-surface current measurements were made with the von Arx (1950) GEK. The current vectors were corrected for the error due to the difference in depth (droop) of the two electrodes. This correction consisted of a vector directed towards the magnetic Equator. The magnitude of this vector was dependent upon the ship's speed, the direction of the ship's motion, and the amount of droop, and was computed by means of formulae derived by John Knauss (personal communication).2/

HUGH M. SMITH CRUISE 1

Cruise 1 of the Hugh M. Smith was planned primarily as a shakedown cruise for the vessel, gear, and personnel. Therefore, the station pattern was designed to take advantage of the lee provided by the island of Hawaii. Figure 1 is a chart of the station positions. The solid lines indicate the lines along which cross sections of bathythermograph temperatures (°F), sigma-t, salinity (°/oo), and dynamic topography (m.) have been drawn. Stations 8A and 8B were occupied several days before adjoining stations in the regular series, so their data were not used in the analyses but are included in the tabulated data.

Since the discussion of the various fields of a water mass is more understandable when the general character of the flow pattern has been established, the usual procedure of presenting the results of the cruises is reversed in this report. The winds and computed currents are discussed first. This is followed by the dynamic topography and the geostrophic currents. Then the fields of temperature, density, salinity, and dissolved oxygen are presented in the order named.

2/ The magnitude of the droop was calculated from observations made at the earth's magnetic equator on a later cruise. The formula used was

$$D = \frac{v_c}{v_s} \frac{H_s}{H_1} S$$

where D = droop
S = distance between electrodes
v_c = resultant signal vector
v_s = speed of the ship
H_h = horizontal magnetic field component
H_s = magnetic field component set on the GEK.

Using the computed values of D, the magnitudes of the corrective vectors were then computed by the formula,

$$\bar{v} = \bar{v}_t - v_s \frac{D}{S} \frac{H_h}{H_s} \bar{u}$$

where
$\bar{v}$ = true current
v_t = current calculated
u = unit vector in the opposite direction of H_h in the Northern Hemisphere and the same direction in the southern.

General Wind Pattern

The wind pattern (table 3) over the islands was influenced by two low pressure systems which developed in the area to the west. The first, December 7 to 10, did not pass over the islands. The second, which first appeared on the U. S. Weather Bureau map of December 15, moved in over the islands and persisted until the end of the cruise. As a result of these lows, the winds were more southerly than normal for December (table 1). When they are transformed into current direction by the 45° *cum sole* rule, the inferred currents are 10° to 80° to the right of the 290°T average indicated by the Pilot Chart.

As mentioned above, during the process of checking the reliability of the winds computed from the synoptic charts (USWB) these winds were compared to the observed winds recorded in the bathythermograph logs. The results were rather startling and it at first appeared that the computed winds were unreliable. However, because of excellent agreement between computed and observed winds in the upwind area and the fact that almost all of the BT observations were in the lee of Hawaii, it has been suggested that the variance was the result of the "barrier" effect of the high mountains of the island (Saul Price, USWB, personal communication). Data from this and subsequent cruises are now being analyzed to determine the nature of the effect.

Dynamic Topography and Geostrophic Currents

The dynamic heights are shown in figure 2 and the geopotential topography in figure 3. The dotted lines in the vicinity of station 1 represent extrapolated values necessary because of bottle failures below 600 m. at station 1 and are intended merely to indicate the direction of flow. The heights are based on the rather dubious assumption that the height of the 700-decibar (m.) surface at station 1 is the mean of the heights at stations 2 and 8. This method was used because the extrapolated values of salinity and temperature at station 1 provided extremely large dynamic heights, indicating currents of up to 1.8 knots in the surface layers. The actual currents were probably somewhere between those indicated by the contour in the figures and those indicated by the extrapolated temperatures and salinities.

The geopotential topography shows an extremely well-developed cyclonic[6/] eddy. At the surface it was centered at station 6, but it shifted towards the island with depth, being centered at station 7 below the 100-decibar surface. The cross sections (fig. 2, panel B) show that it was still evident down to the 500-decibar surface at station 7.

The most striking feature of the velocity field was the persistence of the surface velocities down to the 300-decibar surface in the southern part of the eddy. The velocities at the surface were almost uniform, except for slight maxima of about 0.8 knots (40 cm/sec) between stations 11 and 14. The velocities around the eddy decreased with depth, as expected, except in the vicinity of station 2, where velocities of 0.7 knot (35 cm/sec) were still indicated at the 300-decibar surface.

Temperatures

The temperature cross sections (fig. 4) were constructed from bathythermograph observations.

The general distribution of temperature followed the pattern that was inferred from the geostrophic currents, i.e., the isotherms show doming in the center

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6/ In the northern hemisphere, flow which curves to the left (counterclockwise), when facing downstream, is cyclonic, and flow which curves to the right (clockwise) is anti-cyclonic (Holmboe et al. 1946, p. 191). A cyclonic eddy is characterized by a depression in the geopotential topography at its center, and an anti-cyclonic eddy by a doming.

of the eddy (fig. 4, panels B and C). A strong northerly flow is indicated by the depth and sharpness of the thermocline along the southwest coast of Hawaii.

The effects of diurnal heating were shown by the small pockets of warm water on the surface at stations 6, 10, and 14. In each case the BT lowerings were made during daylight and when the wind was Beaufort force 2 or less.

In order to estimate the amplitude of internal waves that could be expected in the area, the vessel was permitted to drift from 1930Z December 12 to 1000Z December 13 at approximately 19°41'N., 156°15'W., while bathythermograph lowerings were made at half-hour intervals. As was expected (Sverdrup et al. 1946, p. 588), the results (fig. 5) show that the amplitude was greatest at the top of the thermocline and decreased rapidly with depth. The 75°F. isotherm, which was just below the thermocline, had a maximum change of depth of 115 feet, while the 60°F. isotherm had a change of only 80 feet. Although the data indicate the presence of waves of several periods, the time covered by the observations was too brief to permit further analysis of the data.

Sigma-t

The distribution of sigma-t, as shown by the cross sections (fig. 6) and lateral surfaces (fig. 7) is consistent with the dynamic topography. The cyclonic nature of the eddy is shown by the doming of the isopleths in the vicinity of station 6.

The topography of the 23.6, 24.0, 25.0, and 26.0 surfaces indicates that the source of most of the water in the eddy was from flow around the southern coast of Hawaii. Flow through Alenuihaha Channel is not indicated until the depth of the 25.0 and 26.0 surfaces is reached and then it is relatively weak.

The 23.6 surface was selected for contouring because it was the greatest value that intersected the surface and therefore should illustrate the greatest depth from which nutrients could be brought to the surface by isentropic flow. However, since the difference in density is greater than the difference in temperature on the two sides of the eddy would indicate, it is probably indicative of the degree of intrusion of less saline water that was being driven into the area around the southern tip of Hawaii by the southeasterly winds which predominated during the cruise period.

Salinity

The salinity cross sections (fig. 8), surface salinity (fig. 9), and plots of salinity on the sigma-t surfaces (fig. 7) show the degree of the intrusion of water from the southeast. The surface salinities show that water having a salinity of less than 35.0 °/oo had entered between stations 1 and 2 and had penetrated three-quarters of the way around the eddy. Below the surface its progress is shown by the trough of low salinity on the 24.0 sigma-t surface and by the tongue of low salinity water that had penetrated to station 9 on the 25.0 surface.

Dissolved Oxygen

The vertical distribution of dissolved oxygen (fig. 10) is very similar to that shown for 20°N. latitude in the Carnegie section (Sverdrup et al. 1946, p. 710) except for the O_2 maximum of greater than 5.0 ml/l. The Carnegie data show that this corresponds to the S °/oo maximum, and hence it can be attributed to contact with the atmosphere in the region northeast of the islands, where evaporation and cooling caused the surface waters to sink and spread out as an intermediate layer. In figure 10 it is present only as a small elongated cell at about 100 m. on an axis through stations 2 and 15 and corresponds to the trough of low salinity which appeared on the 23.6 and 24.0 sigma-t surfaces.

HUGH M. SMITH CRUISE 10

Cruise 10 of the Hugh M. Smith, July 19-31, 1951, was the first of a series of five cruises to investigate the general hydrographic conditions in the offshore waters of the Hawaiian Islands. Thirty-three stations were occupied at the positions shown in figure 11. Casts to 1,200 m. were made at all stations except 15, 16, 20, and 21, where casts were made to approximately 50 m. above the bottom. Stations 19 and 33 were occupied at approximately the same position. The data from the two were averaged in constructing the station plots, since both fitted into the time sequence when compared to adjacent stations. Stations 8A and 8 were also occupied at approximately the same position, but in this case the time interval between 8 and all the surrounding stations was less than for 8A so only 8 was used.

The solid lines on the station plot (fig. 11) indicate the lines along which profiles of dynamic height, temperature, sigma-t, salinity, and dissolved oxygen have been drawn.

The order and method of presenting the data are the same as for cruise 1.

General Wind Pattern

The weather maps for the cruise period show the well-developed Eastern North Pacific High which is typical of summer conditions. However, comparison of the computed winds (table 4) with the average winds (table 1) shows that the forces were normal for July but that an abnormally large percentage of observed winds were from the east. The computed velocities vary from 9 to 20 knots, with 16 of the 23 values being within the 11-16 knot range of the Beaufort 4 average for the month. Out of 23 observations, 16 or 70 percent show east winds, although the normal for the month is only 30 percent. When the wind directions were transformed into current direction by the 45° cum sole rule, they were 5° to 50° to the right of the 295°T mean for July (table 2).

Dynamic Topography and Geostrophic Currents

The dynamic height cross sections are shown in figure 12 and the dynamic topography of the upper 300 decibars (m.) in figure 13. Because of uncertainty as to the effect of land masses on the topography, no attempt was made to construct the topography inshore of stations, except in areas where there were strong indications that the flow should follow a definite pattern because of the physical configuration of the land masses and the circulation in the surrounding area. For example, the contours were drawn in the area south of Hawaii because the topography to the east and south indicates a strong flow parallel to the south coast of that island due to the divergent effect of the island barrier. In this and similar cases the contours are dotted.

The topography shows that the circulation on the northeast or windward side and on the southwest or leeward side of the island chain is completely different. On the windward side of the islands the circulation was quite confused (figs. 12 and 13). The flow was westerly all along the section from station 27 to station 30, with the highest velocities occurring between stations 27 and 28. The flow between stations 30 and 32 was easterly, but it turned again to the west north of station 32. In the area north of Oahu the flow was deflected northwestward along the islands.

On the leeward side two large cyclonic eddies dominated the circulation pattern (figs. 12 and 13), one centered at station 23 and the other at station 10. The one west of Hawaii, centered at station 23, was much farther north than during cruise 1. The slopes of the surfaces in the eddy centered at station 10 were so great that it seems reasonable to assume that it was a case where external effects such as tides or internal waves were in phase with the effect of the horizontal motion.

Kauai Channel is the only channel for which there are sufficient data to attempt to contour the topography. The resulting flow pattern is very confused. The heights of the surfaces at station 8 indicate northerly or clockwise flow around the west coast of Oahu. On the Kauai side of the channel northerly flow is indicated by the 0-, 50-, and 100-decibar surfaces and westerly by the 200-decibar surface.

Temperatures

The temperature data are again based on the bathythermograms. Figure 14 shows the temperature profiles for the five sections indicated on the track chart. Figure 15 is a plot of the depth of the 75°F. isotherm, which was drawn as an example of a rapid field method for obtaining the major features of the circulation pattern.

Over most of the area the basic configurations of the temperature field followed the pattern expected from the geostrophic flow. For example, both the cross sections and the plot of the depth of the 75°F. isotherm show a doming of the subsurface isotherms at stations 10 and 23.

The temperature field in Kauai Channel differed in some respects from that expected from the geostrophic currents. At station 3, where the isotherms dome, there was mixing, caused by divergence or wind stirring, strong enough to lower the surface temperature. The plot of the 75°F. isotherm indicates that it was part of a cold dome extending northeastward to the area between stations 6 and 7. The cyclonic circulation required to produce this condition agrees with the northerly geostrophic currents at the surface on the Oahu side of the channel but not with those on the Kauai side.

As a result of summer heating, the temperature of the surface layers in the area west of Hawaii were at least 1° to 2°F. higher than those of cruise 1. The effects of local heating are shown in the cross sections by the small cells of water at the surface having a temperature higher than 79°F.

Sigma-t

The effect of summer heating on the density is shown on the cross sections by the lower density of the approximate boundary between the quasi-homogeneous surface layer and the well-defined density gradient. At the time of the winter cruise (cruise 1) the boundary was the 23.8 surface, but on this cruise it was only the 23.2 surface.

In the surface layers (fig. 17), two features stand out in the complicated circulation pattern. The first is the band of surface water with sigma-t greater than 23.0 on the northeast side of the islands. It was not related to the current pattern but was a combination of the high salinity around station 31 and the low temperatures along the islands (bucket and reversing thermometer temperatures). The second was the low values, as low as 22.65 which occurred over the surface of the eddy west of Hawaii. They were due to high surface temperatures which persisted in spite of the force 5 winds reported in the bathythermograph log.

The horizontal plots of depth of sigma-t surfaces (fig. 18) have the topography indicated by the geostrophic currents. They are included only for the detail they add in the area north of the middle group of islands. The 25.0 and 26.0 contours show that the incident currents separated north of Molokai, one branch turning northwest along the islands, and the other turning cyclonically away from the islands, thus completing the pattern shown by the geostrophic currents.

Salinity

The salinity cross sections (fig. 19) show a maximum greater than 35 °/oo just below the quasi-homogeneous surface layer at all stations except 22. However, the Nansen bottle spacing was such that this layer was missed in the sampling at a large number of stations, so it was largely constructed by reference to the T-S diagrams of the adjoining stations. The thickness of the layer was greatest in the western section (fig. 19, panel A), where the > 35.0 °/oo band was 100 m. or more in thickness.

The surface salinity (fig. 20) reflects the extent of the sub-surface maximum by sharp increases in the west and northwest sectors. Over the rest of the area it is almost uniform (34.6 - 34.7 °/oo), except for the area around the middle islands, where a cell of less than 34.6 °/oo occurred, and around stations 10 and 31, where it increased sharply. The minimum could only have been caused by runoff from the islands. The maxima were in areas of strong cyclonic motion and could have been caused by divergence.

Dissolved Oxygen

The vertical distribution of dissolved oxygen (fig. 21) was typical of the North Pacific at these latitudes. It had a maximum of more than 5.0 g/l just below the level of the well-defined density gradient and a deep minimum of 0.6 - 1.0 ml/l at the 500-800 m. level. The maximum is attributed to contact with the surface at the subtropical convergence during the period when evaporation increased the salinity. Although the minimum is frequently attributed to lack of replenishment by horizontal flow, its origin is not completely understood.

HUGH M. SMITH CRUISE 12

Cruise 12 of the Hugh M. Smith was made to observe the hydrographic conditions in the offshore waters of the Hawaiian Islands during the period when the local skipjack fishery was undergoing its fall decline. The station coverage (fig. 22) was similar to cruise 10, but a number of changes were made in the observational program. Dissolved oxygen analyses were omitted and inorganic phosphate analyses were included. The geomagnetic electrokinetograph, which had been installed just before this cruise, was used to make current observations at each station and midway between stations. The stations north of Hawaii, 31 to 32 of cruise 10 (fig. 11), were omitted to permit further study of the eddy indicated in the vicinity of station 1 by the GEK data.

The order and method of presenting the data are the same as for cruises 1 and 10.

General Wind Pattern

The winds during the cruise period (table 5) were of about normal force for October, but they were more southeasterly than normal. From October 13 to 26 they were part of the circulation around the Eastern North Pacific High, but a greater percentage than normal were from the east and southeast. Therefore, the currents inferred by the 45° *cum sole* rule are 15° to 55° to the right of the 280°T mean for October. A shift of the currents even further to the right may be inferred after October 27, when the wind shifted to the south as a low moved into the area from the west.

Dynamic Topography and Geostrophic Currents

The dynamic heights (fig. 23) showed less variation than those of cruise 10 and consequently the geostrophic currents (fig. 24) were shallower and weaker. Significant velocities of 10 cm/sec (0.2 kt.) or greater were limited to depths of

300 m. or less, and at that level velocities of this magnitude were found only between stations 29 and 30. In contrast, during cruise 10 velocities of over 20 cm/sec (0.4 kt.) were found on the 300-decibar surface.

On the windward side of the islands the dynamic topography contours are incomplete because of the omission of the stations north of Hawaii. The flow normal to the section east of Hawaii was confused in the upper 150 m. by the easterly flow indicated between stations 28 and 29. North of Oahu the flow was again northerly, indicating that the major portion of the flow was being deflected by the middle group of islands.

To the leeward of the islands the most prominent features were again the two cyclonic eddies. The one west of Hawaii was larger in diameter, but did not have velocities as great as the corresponding eddy of cruise 10. The eddy south of Oahu was centered off station 1. It was also relatively weak, having a maximum velocity of only 30 cm/sec (0.6 kt.) as against the 72 cm/sec (1.4 kt.) maximum of cruise 10.

In Kauai Channel northerly flow was indicated in the upper 100 m. It was again the result of the high values at station 8, which were indicative of a clockwise flow around Oahu.

GEK Currents

The current vectors computed from GEK observations are shown in figure 25. They represent POFI's first attempt at direct current measurements in the Hawaiian area. The results are only partially satisfactory, if the surface geostrophic currents are used as the standard. They agree fairly well in direction and magnitude in the offshore areas where the velocities were large, such as in the leeward eddies, but in the vicinity of station 8, just west of Oahu, the GEK currents were southerly and the geostrophic northerly. As mentioned above, the accuracy of the latter are also open to doubt in inshore areas, but it is doubtful if the error could be over 90°, as the GEK currents would indicate.

The persistence of the eddy around station 1, shown by the "recheck" of the area, was the most interesting information provided by the GEK. In spite of time differences of up to 7 days and a shift of the incident winds from east to south, the observations made on the second coverage of the area (those marked "A" in fig. 25) agree almost perfectly with those made on the first.

Temperatures

Again the temperature field (figs. 26 and 27) was simply a reflection of the distribution of mass associated with the circulation pattern shown by the geostrophic currents. Divergence and/or wind-mixing in the eddy west of Hawaii was shown by the 2°F. drop in surface temperature at its center.

Sigma-t

The sigma-t distribution (figs. 28 and 29) differs only slightly from that of cruise 10. On the windward side, east of stations 17 and 18, the 23.2 sigma-t surface is still the upper limit of the well-defined density gradient, but over the rest of the area it is the 23.0 surface. The difference was caused by slightly lower surface temperatures in the southeastern sector of the windward side. This difference could be attributed directly to mixing or "upwelling" only in the area around station 19, where the 23.0 sigma-t isopleth reached the surface and surface salinity was slightly greater than in the surrounding area.

The horizontal plots of depth of sigma-t surfaces are again included for the information which the 25.0 and 26.0 surfaces add to the description of the circulation north of the middle group of islands. The cells of greater than 200 m. in

the 25.0 surface and of greater than 320 m. in the 26.0 surface are indicative of anti-cyclonic flow due to the deflective effect of the islands. In both cases the centers of the cells were closer to the islands than during cruise 10.

Salinity

A cell of high-salinity water in the well-defined density gradient was again the most prominent feature of the salinity cross sections (fig. 30). The upper 35.0 °/oo isohaline, which approximated its upper limit over the entire area except east and south of Hawaii and at stations 2 and 14, coincided approximately with the 24.0 sigma-t surface.

In the area east of Hawaii the salinity maximum was between 34.8 and 35.0 °/oo, indicating that water of lower salinity was moving into the area. The station plots indicate that it penetrated at least as far as station 26.

The surface salinities (fig. 31) were 0.1 to 0.2 °/oo higher than on cruise 10 except in the channel between Maui and Lanai, where a small cell of low-salinity water again indicated runoff, and in the section east of Hawaii, where the pattern was as confused as, and probably the result of, the current pattern (fig. 24). At station 29 there was a cell of low-salinity water at the surface which because of the easterly flow indicated by the geostrophic currents could be ascribed to the runoff from the windward coast of Hawaii. At the adjoining station (28) the cell with salinity greater than 34.8 °/oo broke the surface. Considered in conjunction with the dome in the 78.0°F. isotherm, this would indicate divergence in spite of the "high" in the dynamic topography.

Inorganic Phosphate

In the surface layers of the ocean there is a continual loss of the dissolved nutrient salts from the euphotic zone because of the production of organic material and a general downward movement of the particulate matter thus formed. In the open ocean the only processes by which nutrients can be returned to the surface layers are vertical diffusion, convective overturn, and divergence (upwelling). To determine whether mixing or divergence of sufficient magnitude to cause enrichment of the surface layers was induced by the complex flow around the islands, inorganic phosphate analyses were made during cruise 12. Phosphate analyses were made because they are more adaptable to shipboard work than those for nitrate, the other major dissolved nutrient salt.

Only the cross sections of inorganic phosphate (fig. 32) are included, since they are adequate to depict the variations. The 0.6-µg atoms/l isopleth formed the upper boundary of the well-defined gradient. It was between the 24.8 and 25.2 sigma-t surfaces and at a depth of 150 m. or greater, except at station 5, where it was at only 52 m. Although the 0.4-µg atoms/l surface has been drawn in, the distribution above the 0.6-µg atoms/l level was very irregular and bore little resemblance to the other features. This was probably because the lower limit of the accuracy of the method of analysis was being approached (Wooster and Rakestraw 1951).

DISCUSSION

The marked similarities of the circulation patterns of the three cruises have been pointed out repeatedly in the discussion of the results. These quasi-permanent features are more understandable if the nature of the island barrier and the incident currents are explained and their interaction discussed piecemeal.

The first impression given by the chart of the windward or high islands of the Hawaiian Archipelago is of a series of vertical obstacles lying in a southeast to northwest direction. However, when a cross section of the islands is constructed (fig. 33), they are seen to resemble a solid barrier having four small

openings. Only two of these openings, Kauai Channel between Oahu and Kauai, and Alenuihaha Channel between Hawaii and Maui, extend below the 1,000-m. depth that has been assumed as the level of no motion in the computation of dynamic heights. The third, Kaiwi Channel between Molokai and Oahu, has a sill depth of only 614 m. (336 fathoms). The fourth, between Molokai and Maui, is almost negligible; it is split by Lanai Island and has a sill depth of only 80 m. (44 fathoms) and a width of only 8 miles.

Sverdrup (1946, p. 723) states that "a clockwise rotating gyral is present in the eastern North Pacific with its center to the northeast of the Hawaiian Islands. It is probable that the location of this gyral changes with the seasons and shifts from year to year, so that occasionally the gyral may lie entirely to the northeast of the Hawaiian Islands, whereas in other circumstances the Hawaiian Islands may lie inside the gyral." This implies that the flow incident to the islands is either toward the west or slightly northwest. It may be further assumed that it is continually fluctuating, since the Eastern North Pacific High, which provides the driving force, varies constantly in intensity and position.

Further evidence of the seasonal variation in the incident currents and the variations in the incident currents which might be expected during a single month is shown by the charts of mean wind and mean currents (summarized in tables 1 and 2) for the area east of Hawaii. The average monthly current directions, which were taken from the Pilot Charts, illustrate the annual cycle. The most northerly average direction, 310°T, occurs in January, when the greatest percentage, 42 percent, of easterly winds was reported. The most westerly direction (260°T) occurs in September. This is also the period when the Eastern North Pacific High starts to decline in intensity, and this could account for the relatively weak flow of cruise 12. The greatest variation of both winds and currents occurs during the November to March period, when the Eastern North Pacific High is least developed. It is during this period that low pressure cells, such as those that were present during cruises 1 and 12, move into the island area bringing the "kona"[7/] storms (Simpson 1952).

When the nature of the island profile and the westerly flow are considered, the quasi-permanent features can be ascribed to (1) a stream flow impinging upon a lamina at a shallow angle, (2) flow around a single barrier (Long 1952), (3) a jet or wake stream discharged into a fluid at rest (Rossby 1936), or (4) a combination of (2) and (3).

Although there was some flow through the channels, the middle group of islands (Oahu-Maui) seemed very much like a solid barrier, so that the circulation to the east resembled in many respects a "stream flow on a lamina" (Lamb 1932). In such a case, the flow is split by the barrier; the point of separation and the amount going in either direction are dependent upon the angle of impact. The incident flow of both cruises 10 and 12 was from an easterly direction, so that the major part of the flow was deflected to the right or northwest and only a small part to the left or southeast. The easterly flow southeast of station 32 during cruise 10 was the result of the segment of the incident current that was deflected to the left.

The angle of deflection or degree of anti-cyclonic motion imparted to the segment of the incident current that was deflected to the right controlled the flow through Kauai Channel during cruises 10 and 12. During cruise 12, when the geostrophic currents north of Oahu had a strong northerly component, the flow was northerly through the channel. During cruise 10, when the angle of deflection was small at the surface and decreased still further with depth, the flow was across the channel above the 200-decibar surface, where a slight westerly flow was indicated.

7/ Kona, a Polynesian adjective meaning "leeward," is used locally to describe periods during which the usually persistent tradewinds are replaced by southerly winds and rain squalls. Each year the drier leeward sides of the Hawaiian Islands receive more than half of their rainfall from two or three of these storms.

In the lee of the islands there was a striking resemblance between many of the features of the flow pattern and the "east wind case" described by Long (1952) in his discussion of the results of model studies of flow past a barrier in a rotating spherical shell. This was particularly noticeable in the results of cruise 1, which had the stations most closely spaced and a series close inshore. On the equatorward side Long found that the fluid in the immediate vicinity of the barrier curved northward along the obstacle for about a quadrant (90°) while the bulk of the fluid continued in a general westerly direction. This phenomenon could account for the strong northerly flow along Hawaii during cruise 1 and the greater dynamic height at station 8 during both cruises 10 and 12. Along the boundary between the bulk of the fluid that was continuing westward and the wake of the barrier he found a series of horizontal clockwise eddies having their axes directed easterly. He attached no significance to their direction and doubted that they could exist in a stratified fluid such as the ocean. However, it is felt that the persistence of the easterly flow down to the 300-decibar surface on cruise 1 is a manifestation of this phenomenon.

On the poleward side he found that the flow separated from the barrier and moved zonally to form a series of cyclonic eddies. This would suggest that the eddies found in the survey area are merely the first of a series that occur downstream from the islands. However, it must be remembered that only part of the incident flow passes through the channels, so that a complete analogy to the single barrier case is not valid.

It has been demonstrated that a similar series of eddies would result from the flow through the channels. Rossby (1936) showed in his Wake Stream Theory that as a jet or wake, which has been discharged into a fluid at rest, passes downstream it acts as a series of sinks with respect to the surrounding fluid. Large quantities of fluid are removed from the surroundings, and this removal is associated with the creation of a countercurrent along the left side. The mass transport increases downstream, but is intermittently reduced through the discharge of eddies along the boundary of the currents. On the right side a compensation is set up which decreases in intensity and becomes negligible. Thus, the eddy west of Hawaii can be attributed to the flow through Alenuihaha Channel and the one west of Oahu to the flow through Kauai Channel. Again minor discrepancies between the selected model and prototype are evident. In the first case it has already been shown that during cruise 1 part of the flow was the result of the clockwise flow around the island of Hawaii. In the second case the magnitude and strength of the eddy, particularly during cruise 10, seemed larger than could be expected from such a limited source as Kaiwi Channel.

The variations in strength, magnitude, and position of the eddies during the three cruises reflect the varying direction and strength of the incident currents which were inferred from the monthly wind and current data. However, the stability of the eddy south of Oahu, as shown by GEK observations made as much as 1 week apart and after a 90° shift in the incident winds, indicates that these changes must occur very gradually.

When the sigma-t cross sections are compared to the inorganic phosphate cross sections of cruise 12 (fig. 32) to determine whether enrichment of the surface layers by lateral mixing (along sigma-t surfaces) occurred in the eddies or in any other areas, the results are insignificant compared to those reported for equatorial waters by Cromwell (1951) and Austin (1954). The greatest depth from which nutrients could have reached the surface by lateral mixing during any of the cruises was about 100 m., i.e., at stations 12 and 14 during cruise 1 (fig. 6, panels C and D) or at stations 1 and 25 during cruise 10 (fig. 16, panels A and D). Such mixing could not have produced much enrichment, because the phosphate-rich layer was below 150-200 m. during cruise 12.

The great depth of the phosphate-poor layer in the Hawaiian Island area can be explained by the circulation which produced the high-salinity water that lies at its lower limit. This layer is the result of subsidence and spreading out of water which has had its density increased by evaporation and cooling as it moved

around the Northeast Pacific Gyral. Sverdrup (1946, fig. 209A), indicated that the source of this water is at about 40°N., 140°W. This results in a sub-surface recirculation over the area of water that is already low in inorganic phosphate. The acceleration of the natural tendency for organic phosphate to settle out as particulate matter by the downward motion in the area of subsidence would also contribute to the barrenness of the recirculating water.

The only perceptible evidence that enough mixing to enrich the surface layers is induced by the impingement of the west to northwesterly currents on the islands was shown in the analyses of zooplankton abundance by King and Hida (1954). They found that although the abundance of zooplankton was almost uniform throughout the region, the upstream area to the south and east of the island of Hawaii yielded, on the average, the lowest volumes (cruises 10 and 12, stations 26 to 30). A comparison of the plots of the abundance of zooplankton (King and Hida 1954, fig. 10) with the lateral plots of geostrophic currents for cruises 10 and 12 (figs. 13 and 24) indicates that there were slight maxima at, or near, the cyclonic eddies in the lee of the islands during both cruises and at station 31 during cruise 10. However, two other maxima occurred that could not be attributed to, nor remotely connected with, any unusual hydrographic features, the first at station 5 during cruise 10 and the second at station 6 during cruise 12. The first was particularly interesting since it was 21 ml/1,000m^3 higher than or 1.5 times that of any other station, and it occurred at the same station as the inexplicable high inorganic phosphate content in the upper 100 m. during cruise 12.

The writer believes that the occurrence of the zooplankton maxima at or near the centers of the cyclonic eddies and the frequent occurrence of high salinities and low temperatures at their centers are the result of divergent motion which causes some enrichment of the surface water. The slightness of the maxima and the number of exceptions to the increase of salinity and decrease of temperature at the centers indicate that vertical motion is small and intermittent at best.

Acknowledgements

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FIGURES

Frontispiece: The Windward or High Islands of the Hawaiian Archipelago.

Hugh M. Smith Cruise 1

1. Station positions.
2. Profiles of isobaric surfaces relative to the 1,000 decibar surface.
3. Geopotential topography of 0, 50, 100, 200, and 300 decibar surface.
4. Temperature profiles.
5. Variation in depth of the 75°, 70°, 65°, and 60°F. isotherms with time.
6. Sigma-t profiles.
7. Topography of the 23.6, 24.0, 25.0, and 26.0 sigma-t surfaces and salinity on these surfaces.
8. Salinity profiles.
9. Salinity at the sea surface.
10. Dissolved oxygen profiles.

Hugh M. Smith Cruise 10

11. Station positions.
12. Profiles of the isobaric surfaces relative to the 1,000 decibar surface.
13. Geopotential topography of the 0, 50, 100, 200, and 300 decibar surfaces.
14. Temperature profiles.
15. Topography of the 75°F. isotherm.
16. Sigma-t profiles.
17. Sigma-t at the sea surface.
18. Topography of the 23.2, 24.0, 25.0, and 26.0 sigma-t surfaces.
19. Salinity profiles.
20. Salinity at the sea surface.
21. Dissolved oxygen profiles.

Hugh M. Smith Cruise 12

22. Station positions.
23. Profiles of the isobaric surfaces relative to the 1,000 decibar surface.
24. Geopotential topography of the 0, 50, 100, and 200 decibar surfaces.
25. Current vectors computed from GEK measurements.

26. Temperature profiles.

27. Topography of the 75°F. isotherm.

28. Sigma-t profiles.

29. Topography of the 23.2, 24.0, 25.0, and 26.0 sigma-t surfaces.

30. Salinity profiles.

31. Salinity at the sea surface.

32. Inorganic phosphate profiles.

Miscellaneous

33. Profile of the Hawaiian Islands, Kauai to Hawaii.

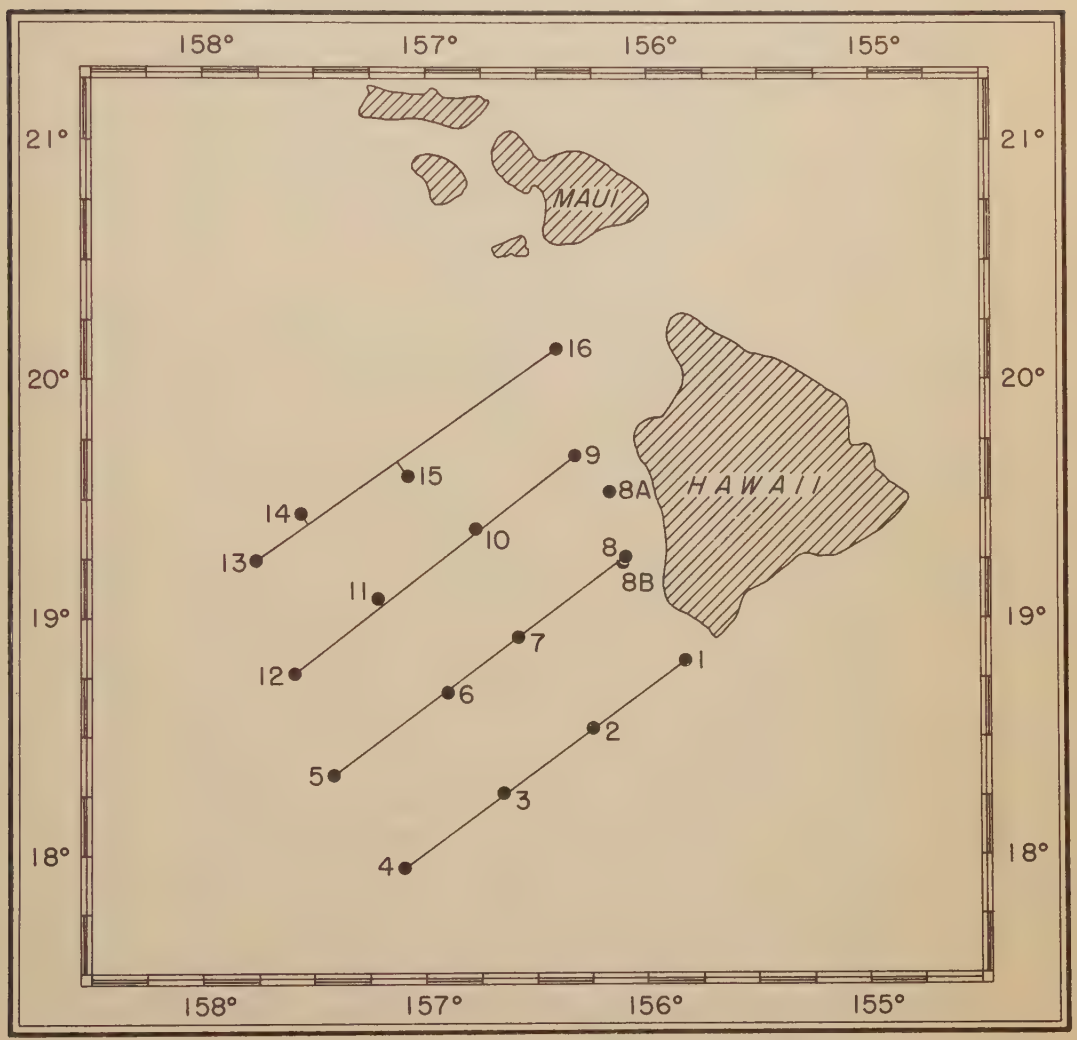

Fig. 1. -- H. M. Smith cruise 1, December 13-21, 1949, station positions. Solid lines indicate lines along which profiles of dynamic heights (dyn. M), temperature (°F), sigma-t, salinity (°/oo), and dissolved oxygen (ml/l) have been drawn.

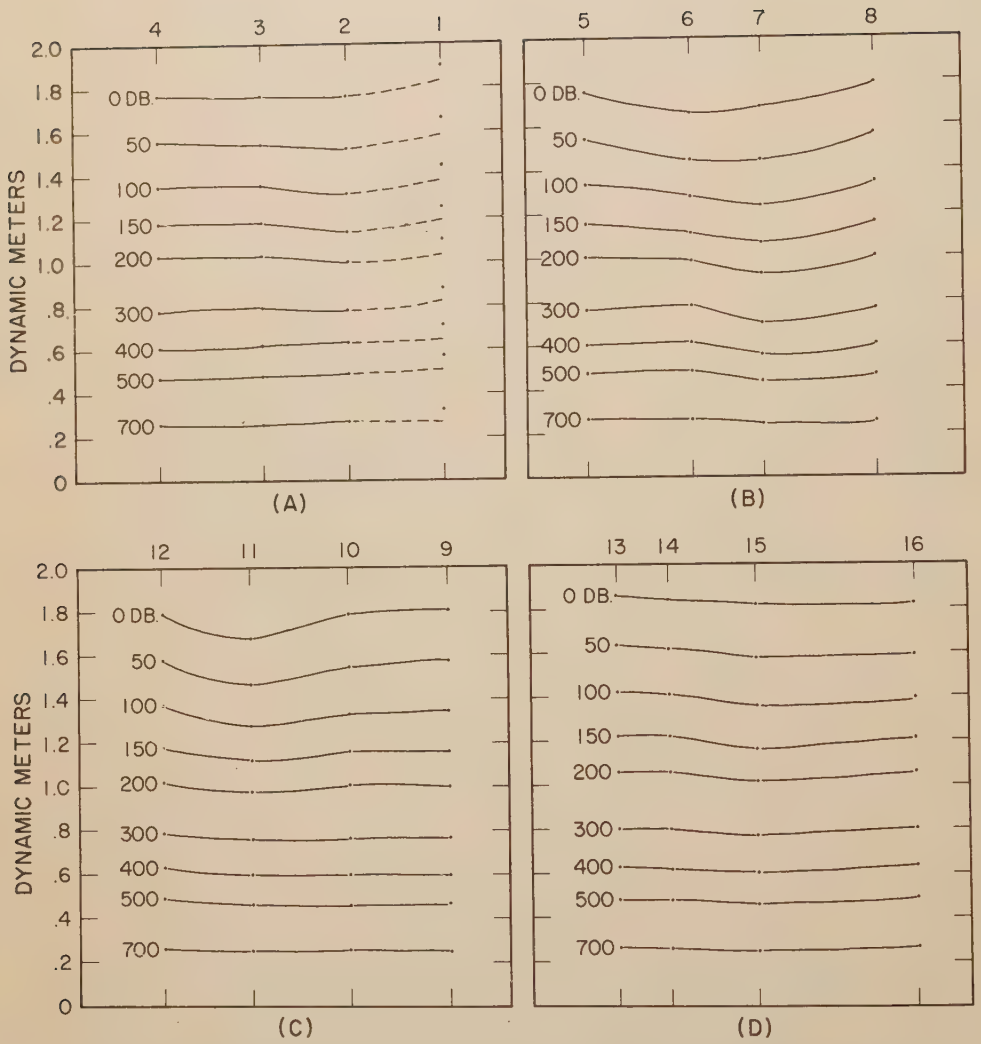

Fig. 2.--H. M. Smith cruise 2. Profiles of isobaric surfaces relative to the 1,000 db. surface. A. Stations 1-4, B. Stations 5-8, C. Stations 9-12, and D. Stations 11-16.

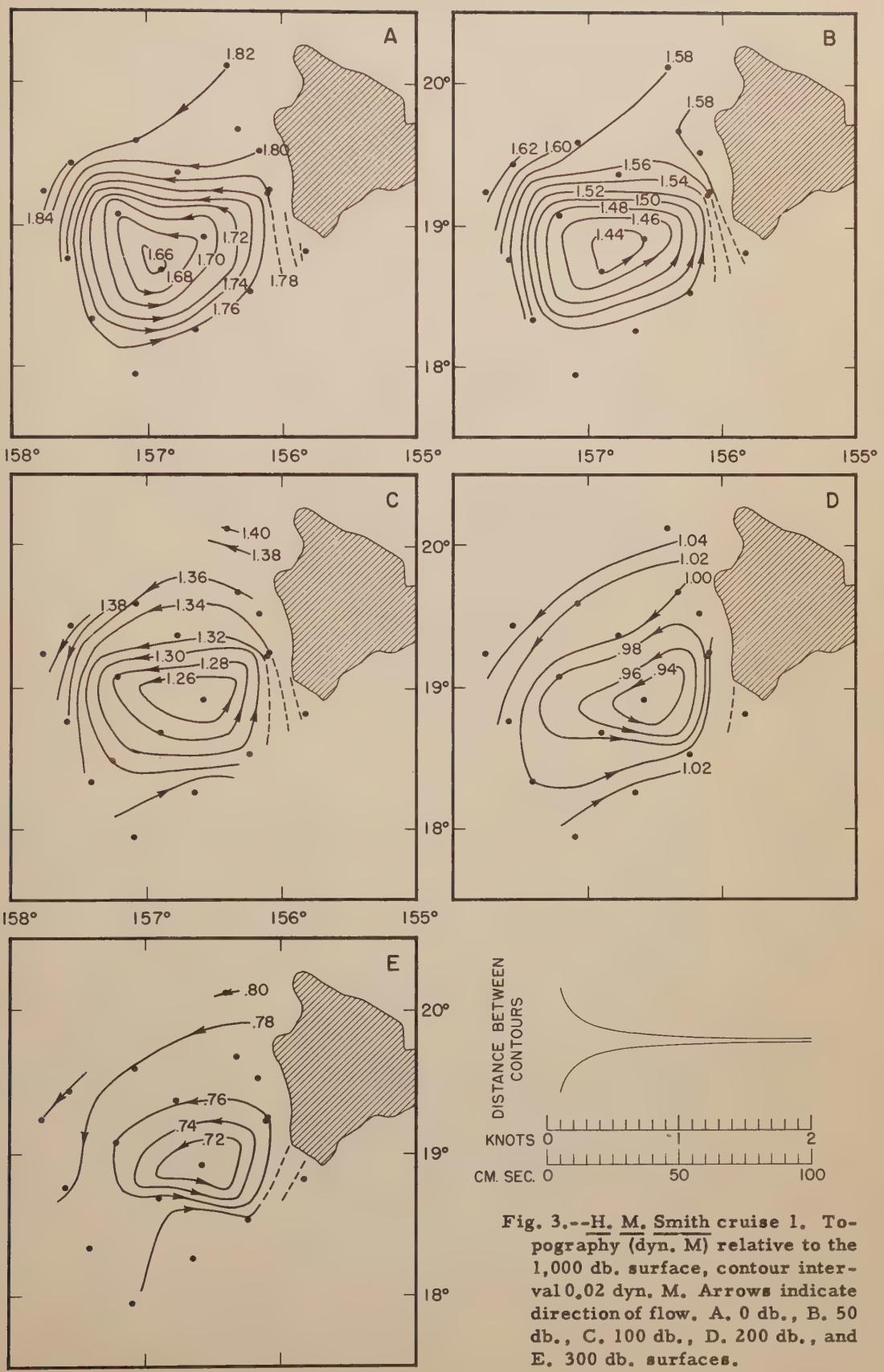

Fig. 3.--H. M. Smith cruise 1. Topography (dyn. M) relative to the 1,000 db. surface, contour interval 0.02 dyn. M. Arrows indicate direction of flow. A. 0 db., B. 50 db., C. 100 db., D. 200 db., and E. 300 db. surfaces.

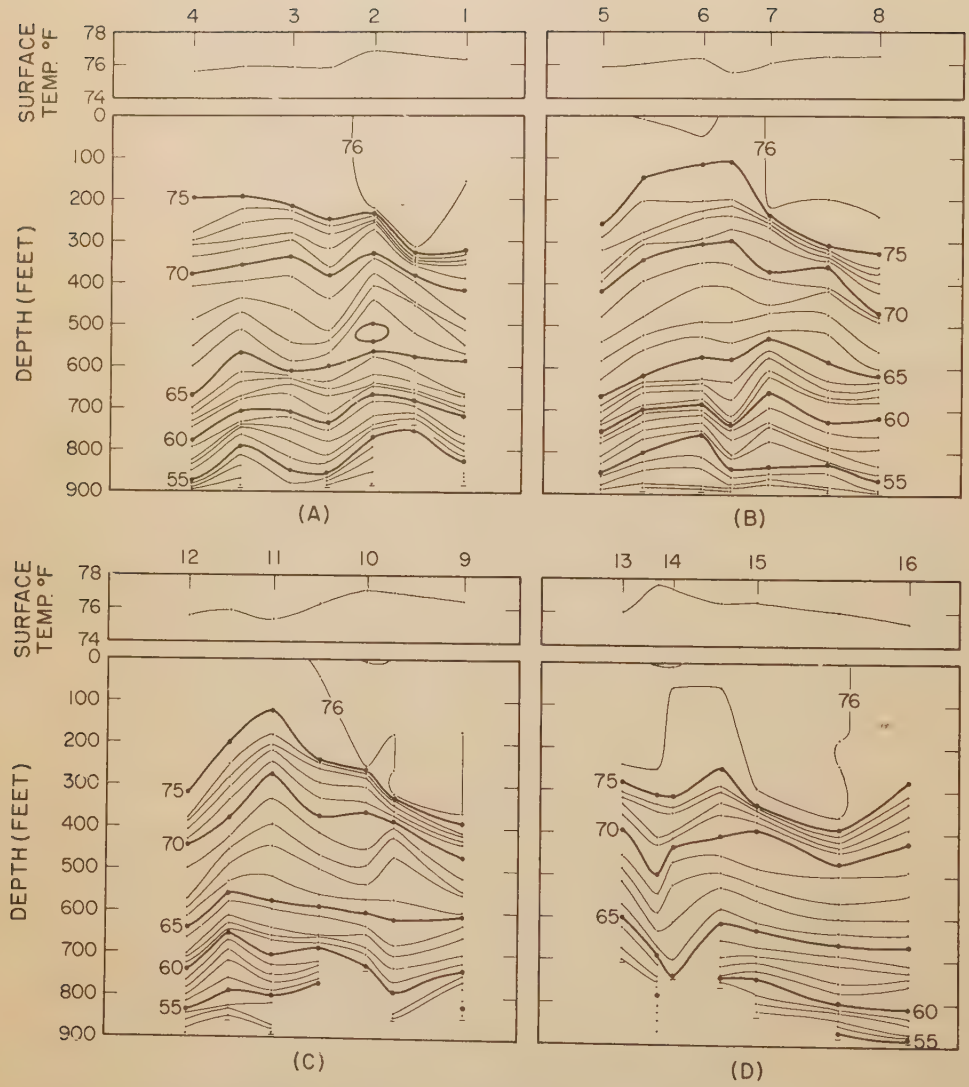

Fig. 4.--H. M. Smith cruise 1. Surface and vertical temperature profiles. Upper panels - surface temperatures (^{o}F) from "bucket" thermometer reading at each bathythermograph lowering. Lower panels - temperature profile based on bathythermograph lowerings, isotherm interval 1^{o}F, depth of lowering shown by small horizontal dashed line. A. Stations 1-3, B. Stations 5-8, C. Stations 9-12, and D. Stations 13-16.

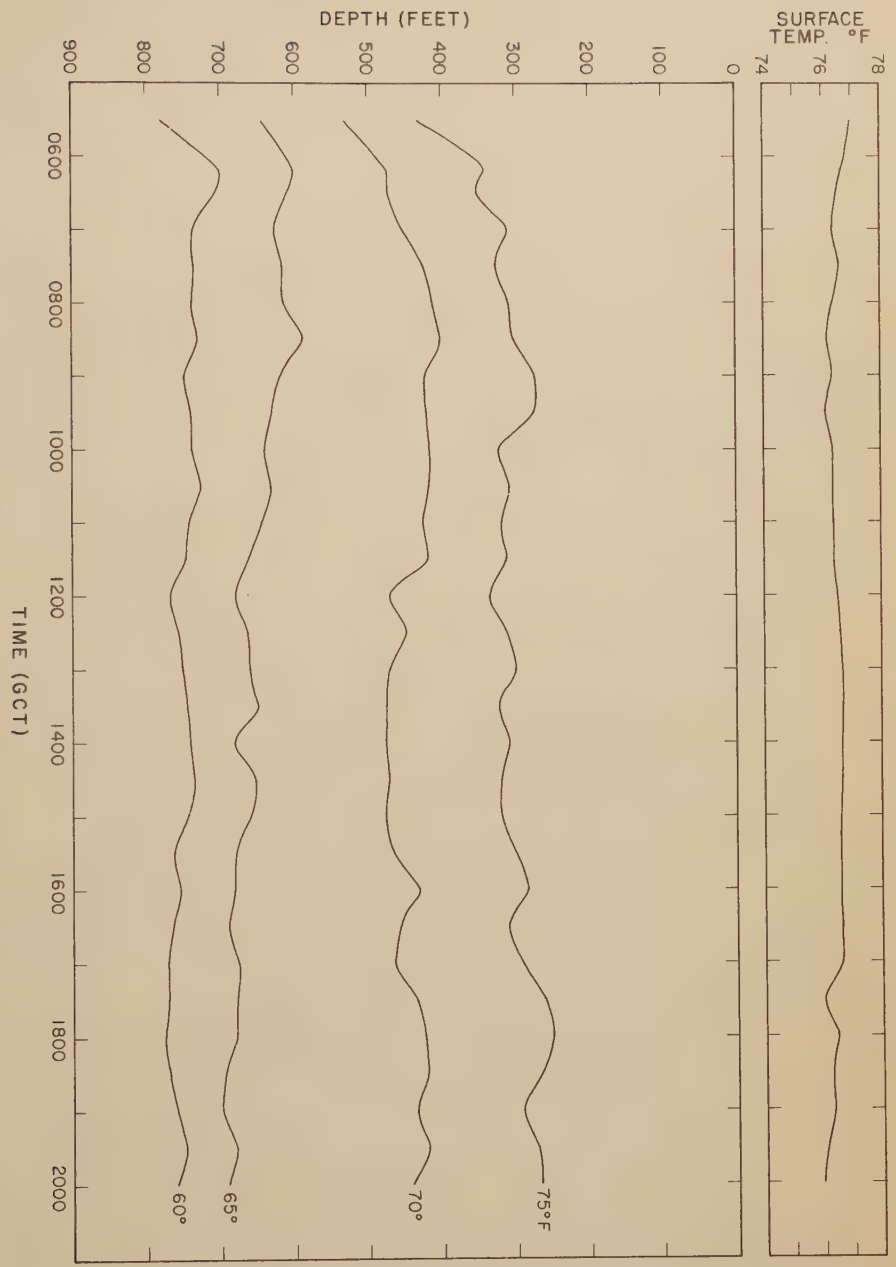

Fig. 5.--H. M. Smith cruise 1. Upper panel - variation of the surface temperature with time, Lower panel - variation in depth of isotherms with time from bathythermograph lowerings made December 13, 1949 while drifting from 19°41'N., 156°15'W. to 19°43'N., 156°20'W.

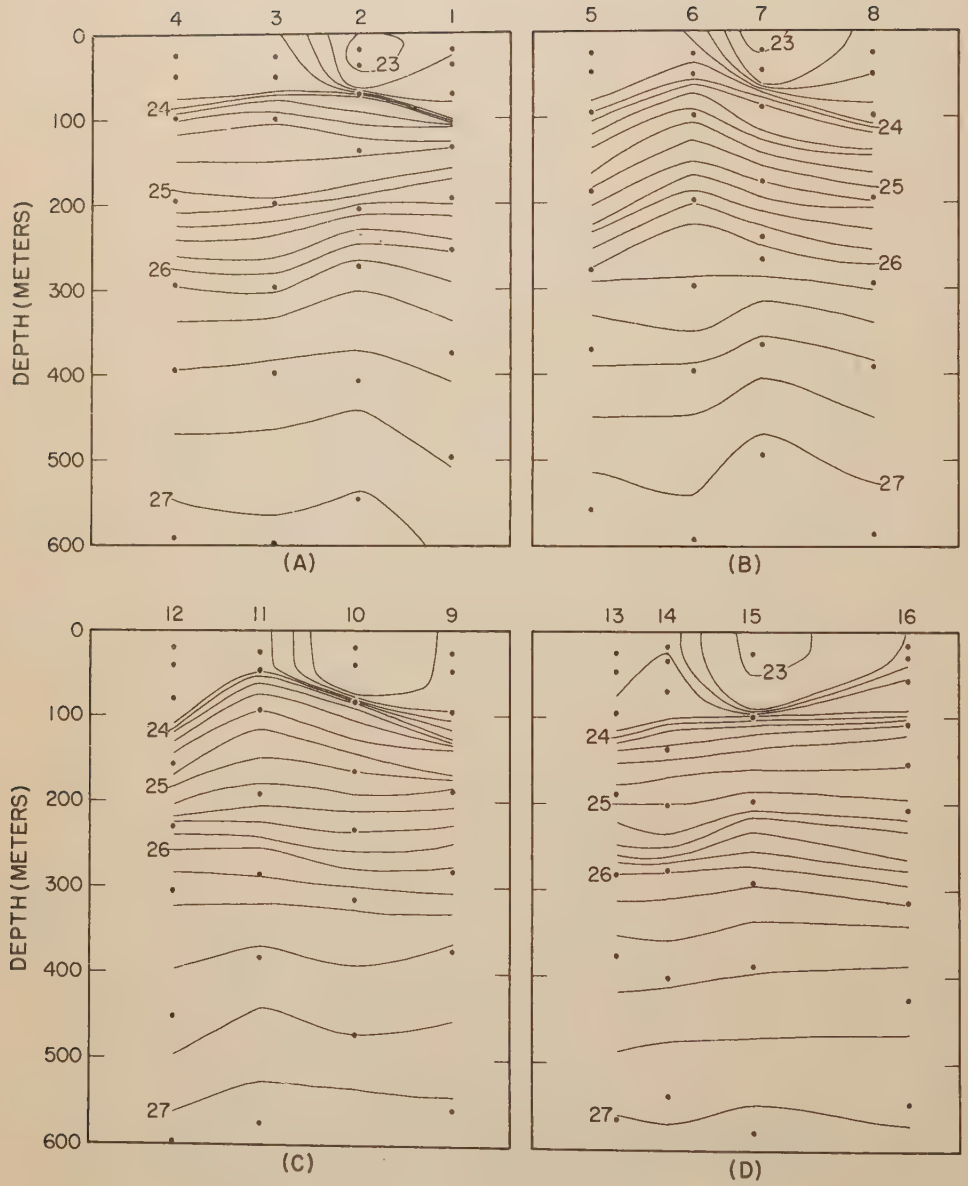

Fig. 6.--H. M. Smith cruise 1. Profiles of sigma-t, isopleth interval 0.2. A. Stations 1-4, B. Stations 5-8, C. Stations 9-12, and D. Stations 13-16.

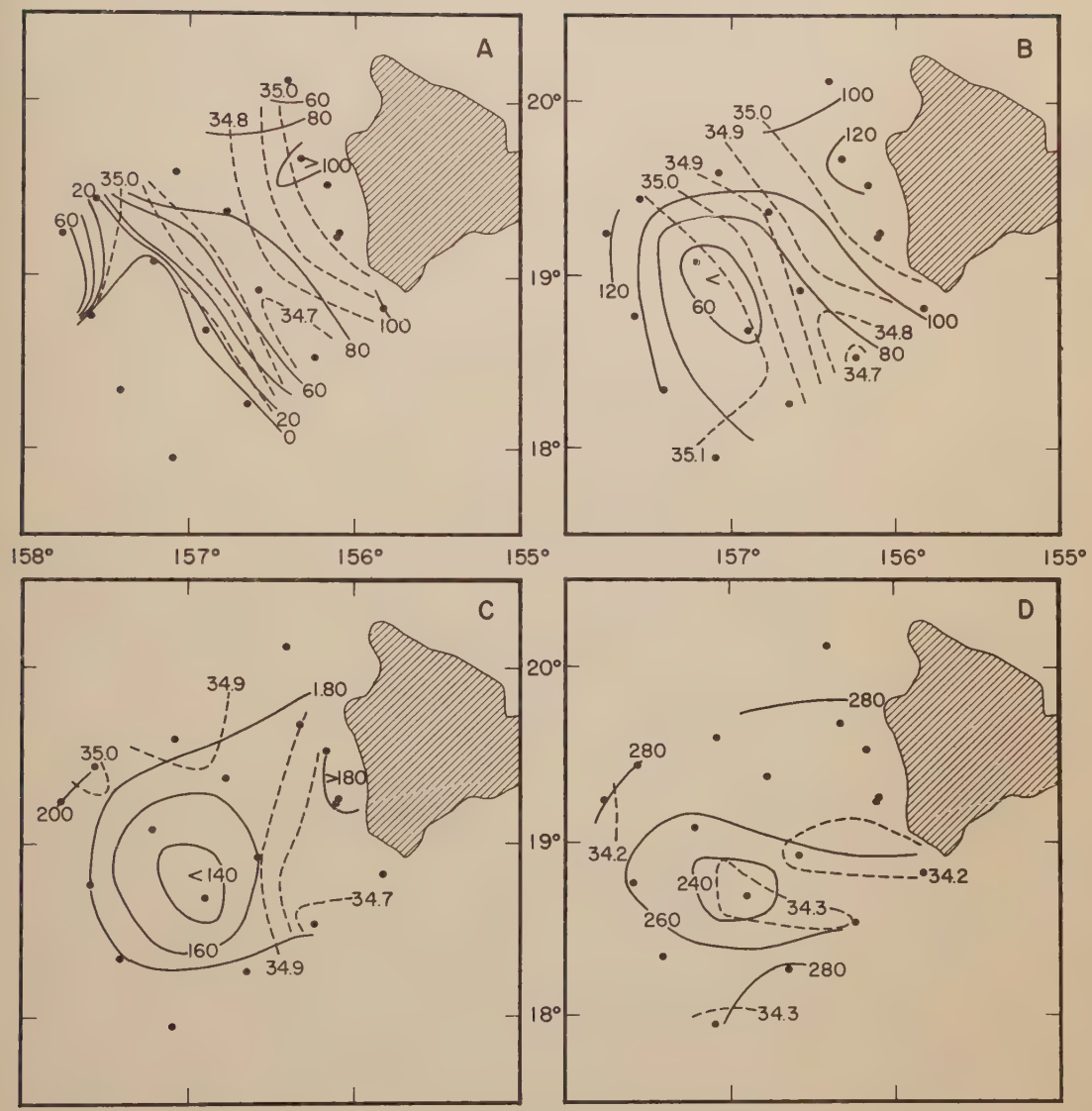

Fig. 7.--H. M. Smith cruise 1. Solid lines, topography of 23.6, 24.0, 25.0, and 26.0 sigma-t surfaces, contour interval 20 M. Dotted lines, salinity on the sigma-t surfaces, isohaline interval 0.1 °/oo. A. 23.6, B. 24.0, C. 25.0, and D. 26.0 sigma-t surfaces.

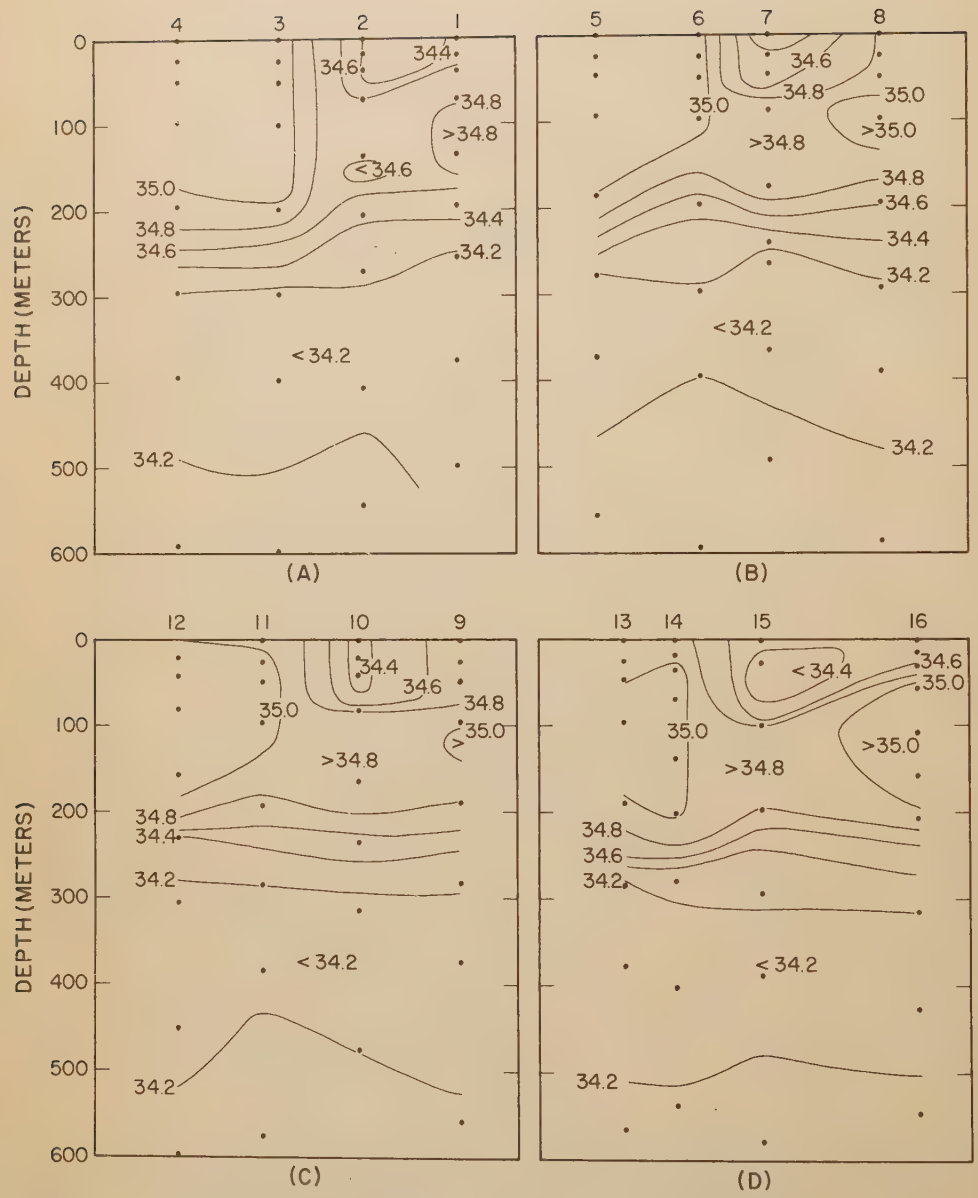

Fig. 8.-- H. M. Smith cruise 1. Profiles of salinity in °/oo, isohaline interval 0.2 °/oo. A. Stations 1-4, B. Stations 5-8, C. Stations 9-12, and D. Stations 13-16.

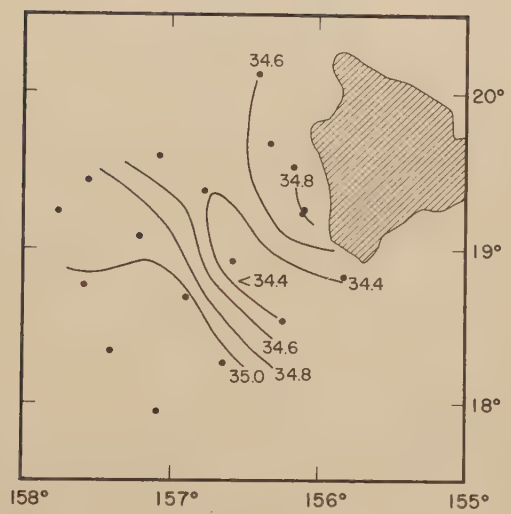

Fig. 9.--H. M. Smith cruise 1. Surface salinity in °/oo, isohaline interval 0.2 °/oo.

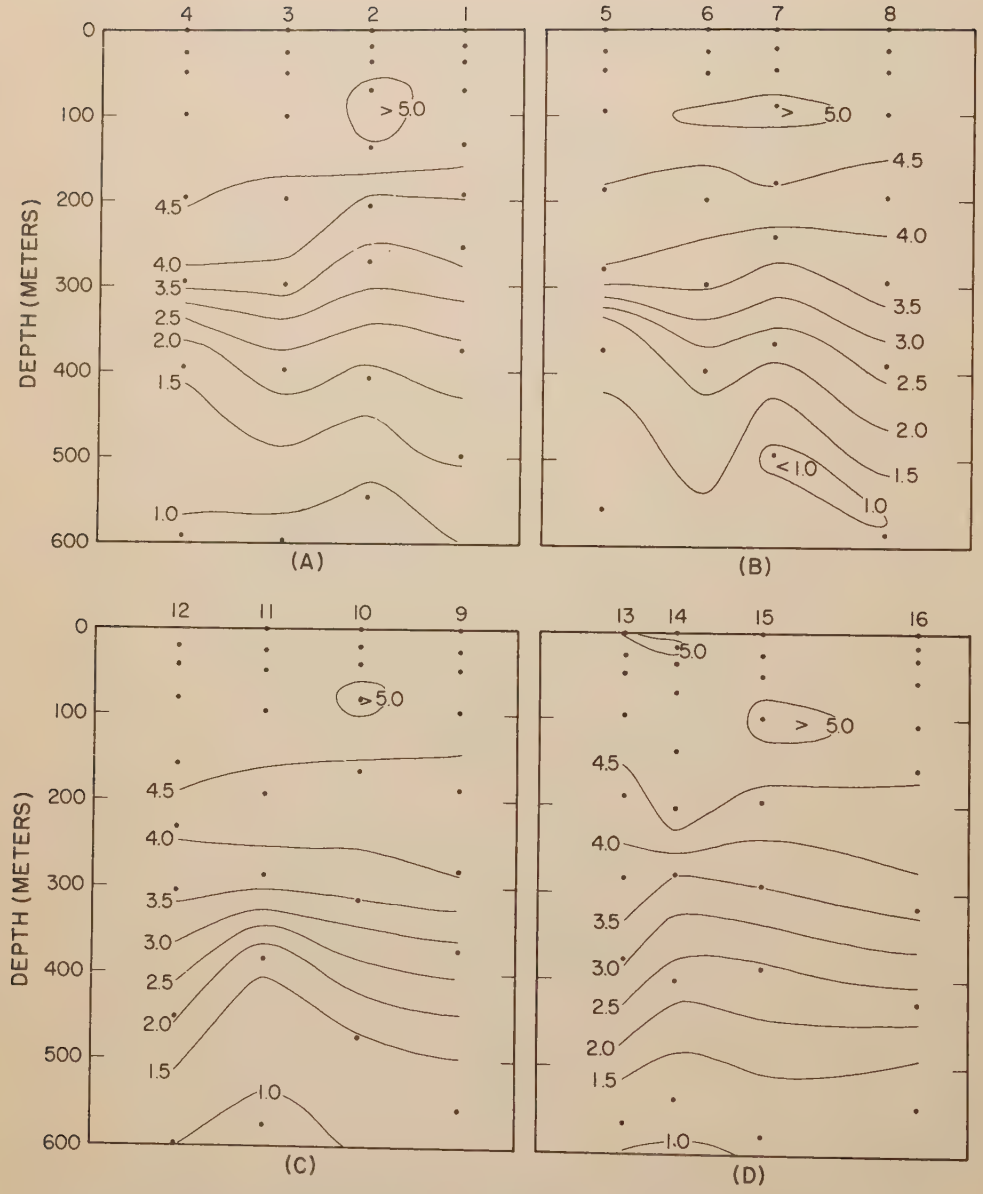

Fig. 10.--H. M. Smith cruise 1. Profiles of dissolved oxygen in ml/l, isopleth interval 0.5 ml/l. A. Stations 1-4, B. Stations 5-8, C. Stations 9-12, and D. Stations 11-16.

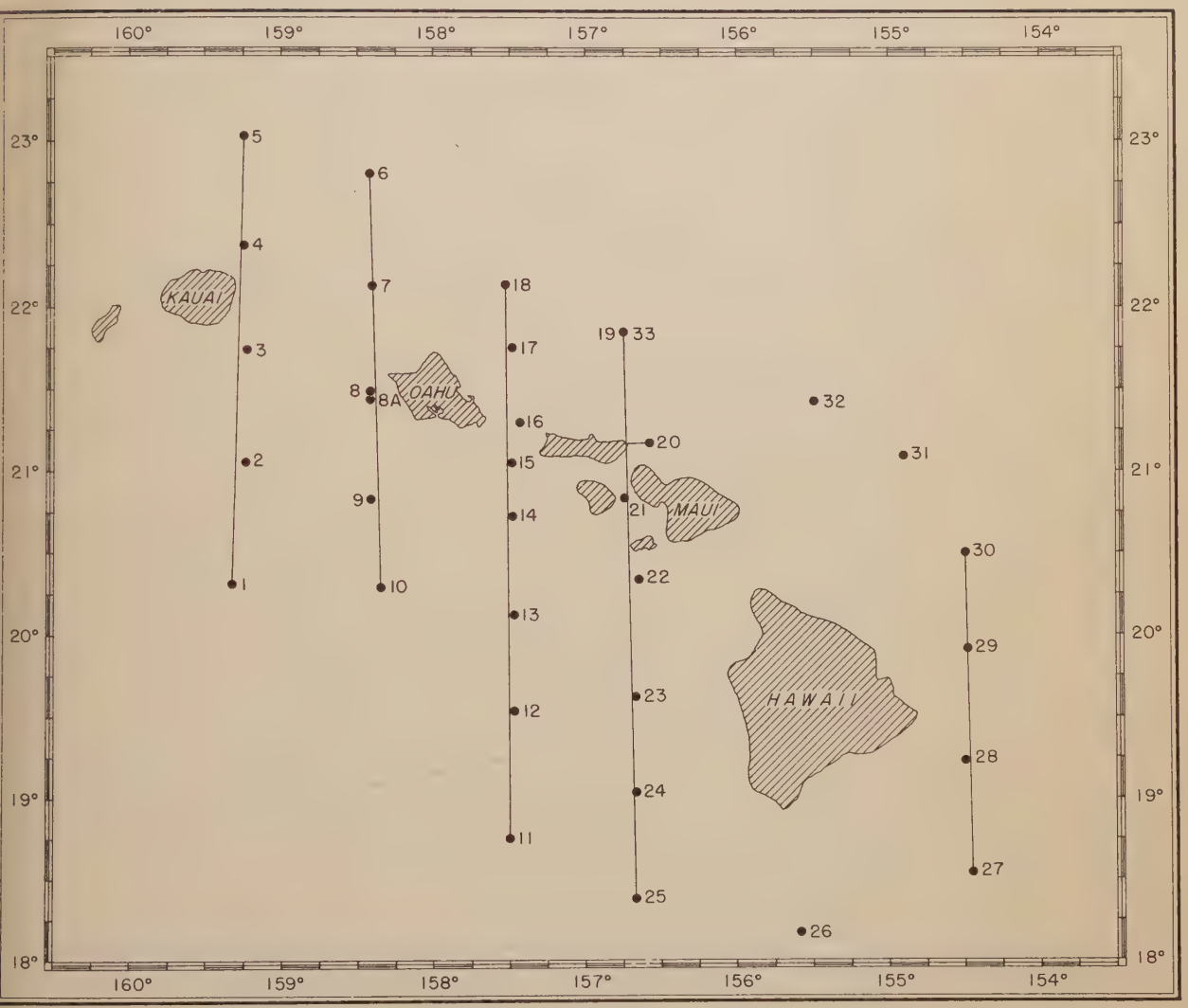

Fig. 11.--H. M. Smith cruise 10, July 19-31, 1951, station positions. Solid lines indicate lines along which profiles of dynamic heights (dyn. M), BT temperatures (°F), sigma-t, salinity (°/oo), and dissolved oxygen (ml/l) have been drawn.

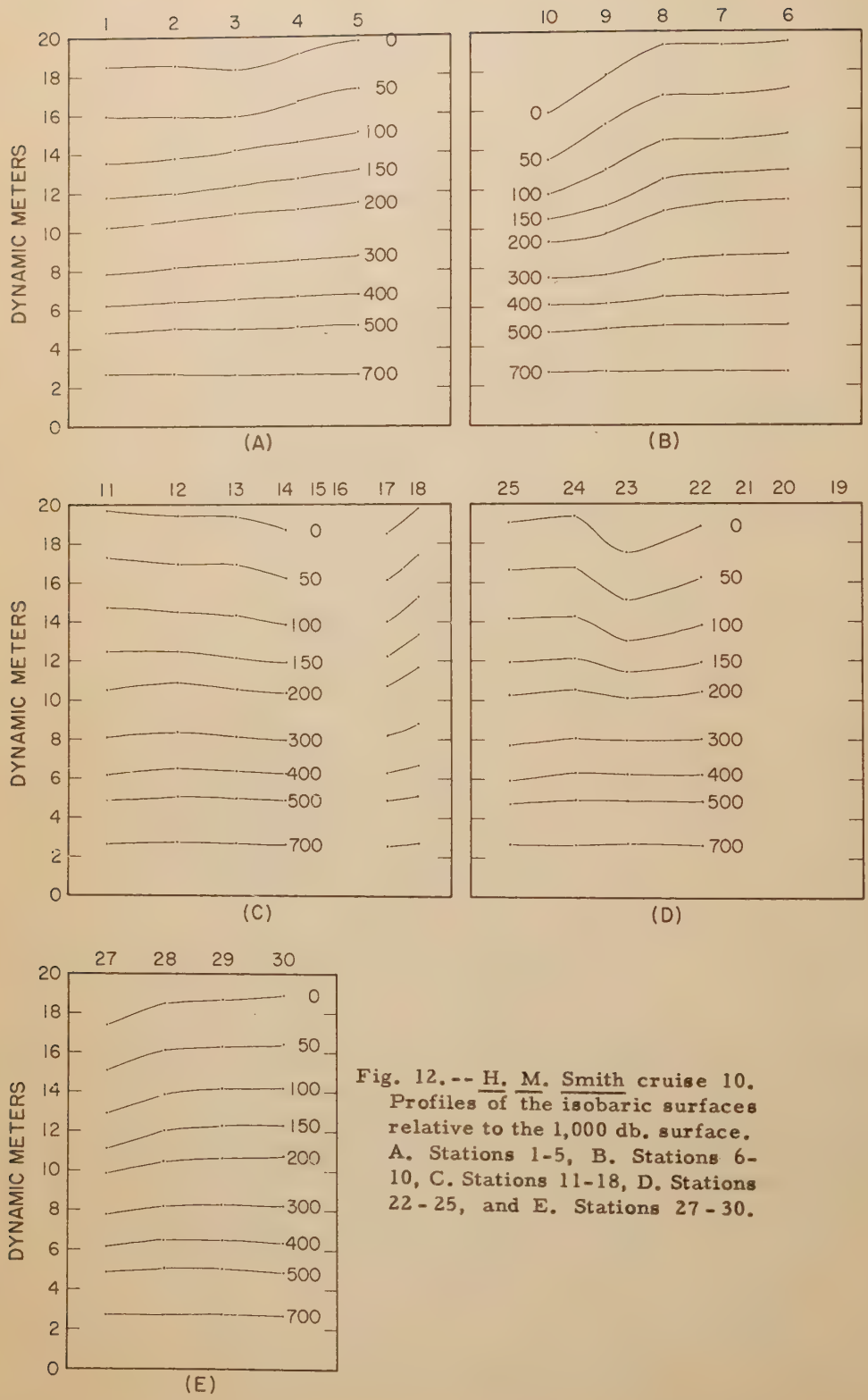

Fig. 12.-- H. M. Smith cruise 10. Profiles of the isobaric surfaces relative to the 1,000 db. surface. A. Stations 1-5, B. Stations 6-10, C. Stations 11-18, D. Stations 22-25, and E. Stations 27-30.

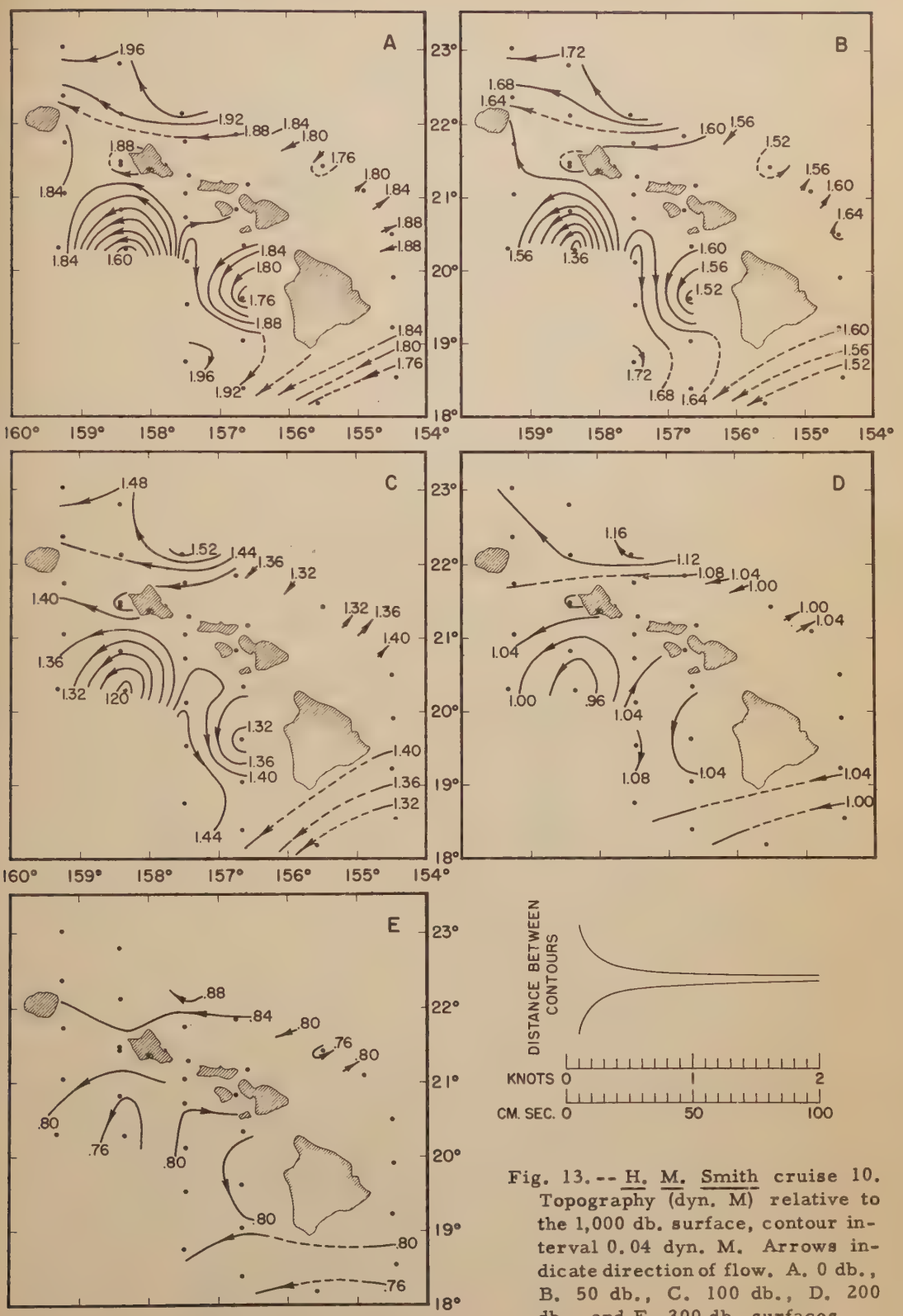

Fig. 13.--H. M. Smith cruise 10. Topography (dyn. M) relative to the 1,000 db. surface, contour interval 0.04 dyn. M. Arrows indicate direction of flow. A. 0 db., B. 50 db., C. 100 db., D. 200 db., and E. 300 db. surfaces.

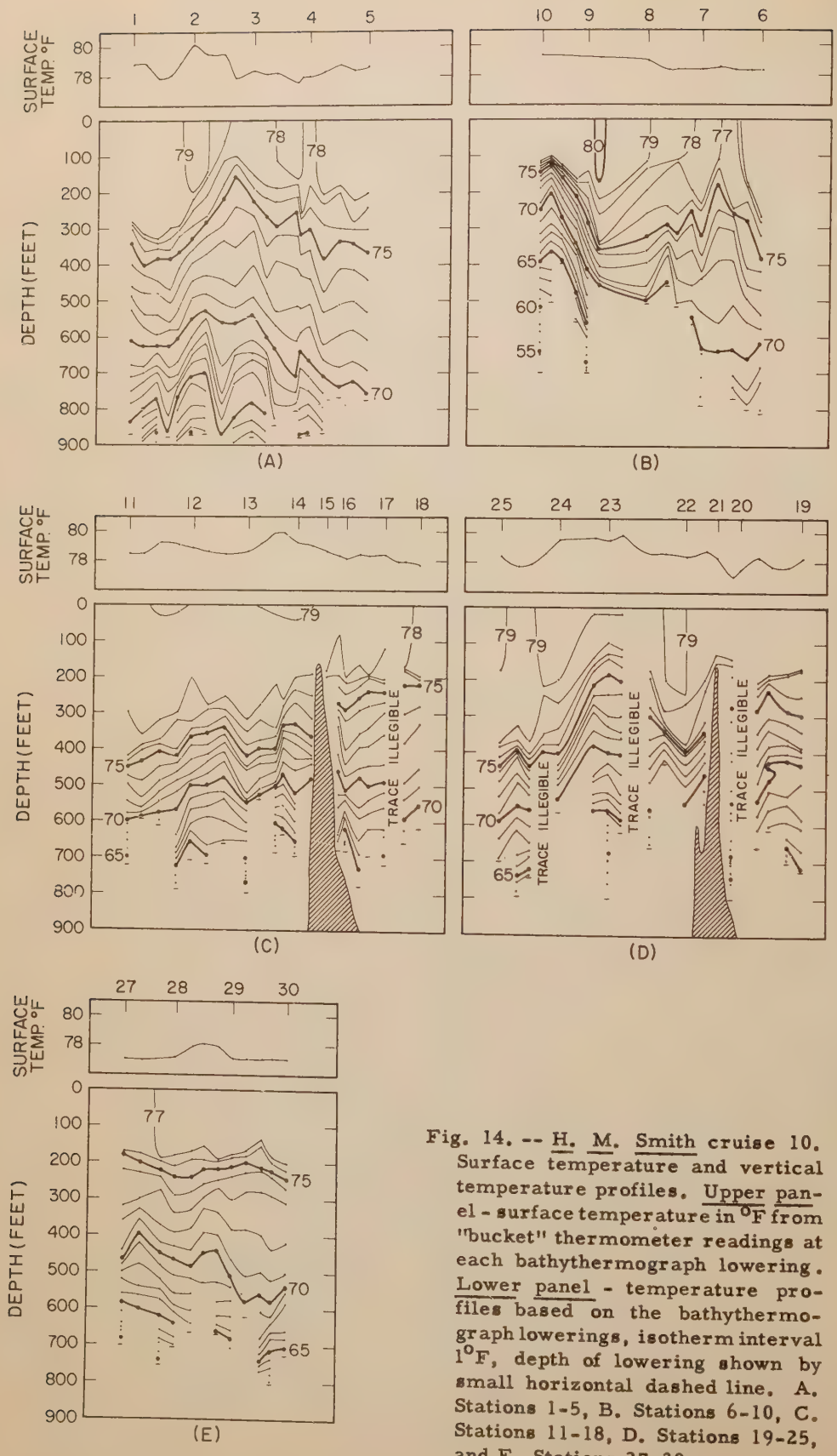

Fig. 14. -- H. M. Smith cruise 10. Surface temperature and vertical temperature profiles. Upper panel - surface temperature in °F from "bucket" thermometer readings at each bathythermograph lowering. Lower panel - temperature profiles based on the bathythermograph lowerings, isotherm interval 1°F, depth of lowering shown by small horizontal dashed line. A. Stations 1-5, B. Stations 6-10, C. Stations 11-18, D. Stations 19-25, and E. Stations 27-30.

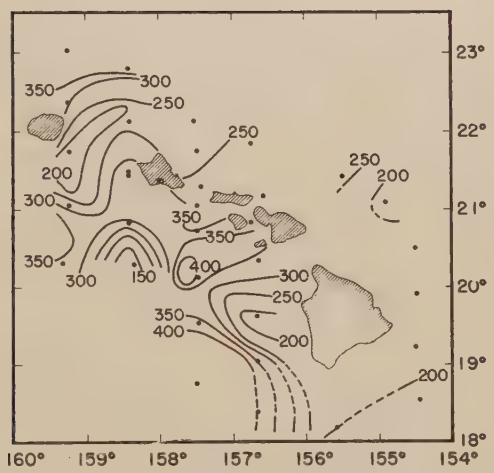

Fig. 15.-- H. M. Smith cruise 10. Topography in feet of the 75°F isotherm, contour interval 50 feet.

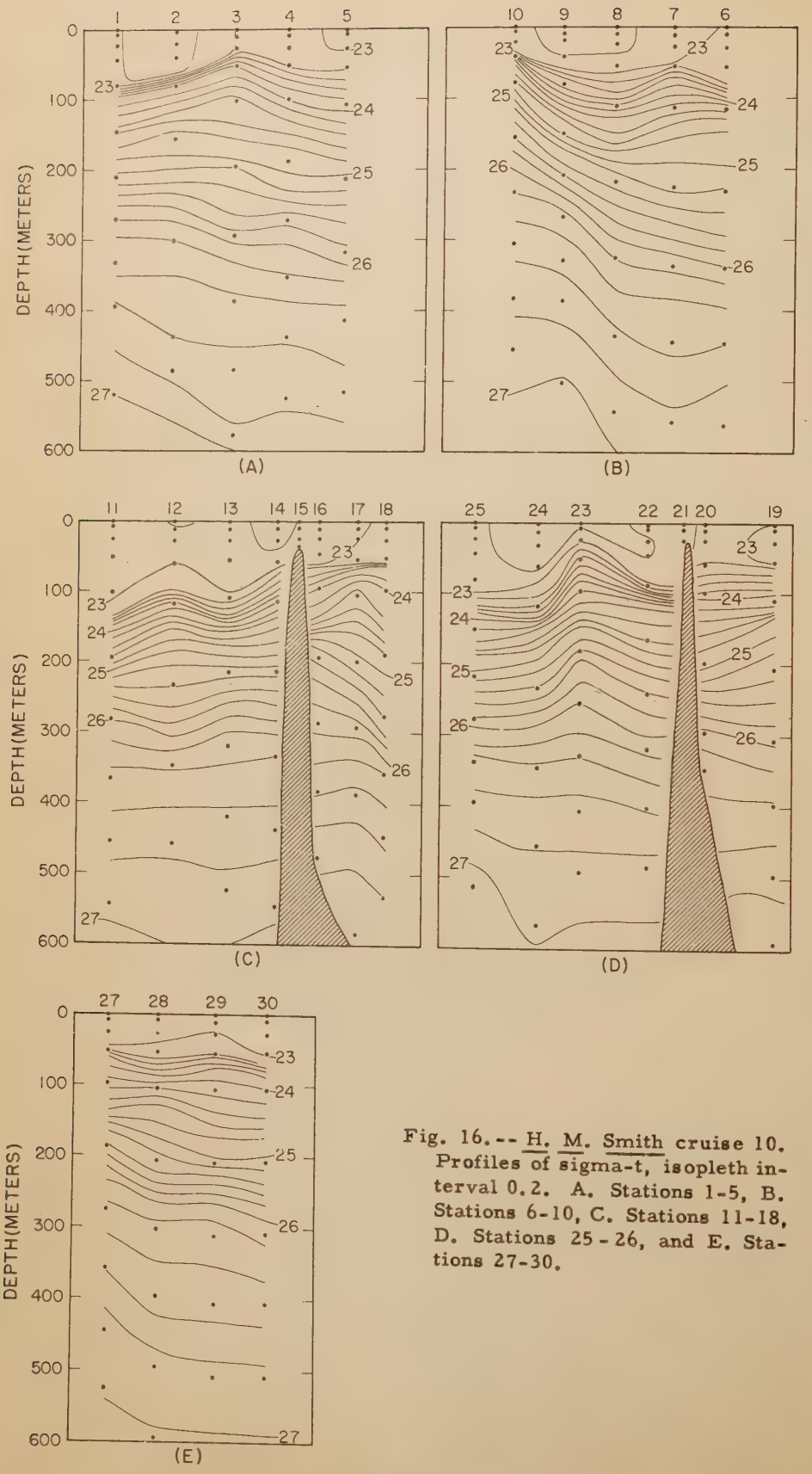

Fig. 16.-- H. M. Smith cruise 10. Profiles of sigma-t, isopleth interval 0.2. A. Stations 1-5, B. Stations 6-10, C. Stations 11-18, D. Stations 25 - 26, and E. Stations 27-30.

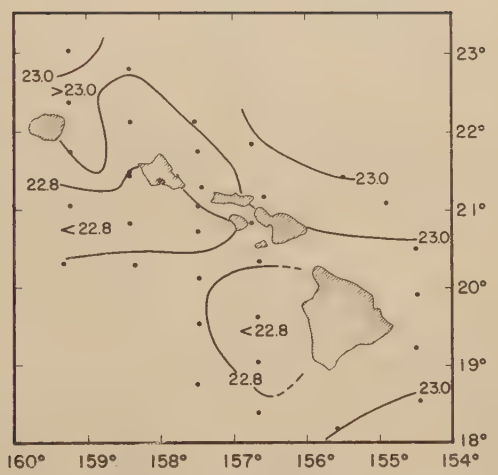

Fig. 17.--H. M. Smith cruise 10. Surface sigma-t, isopleth interval 0.2.

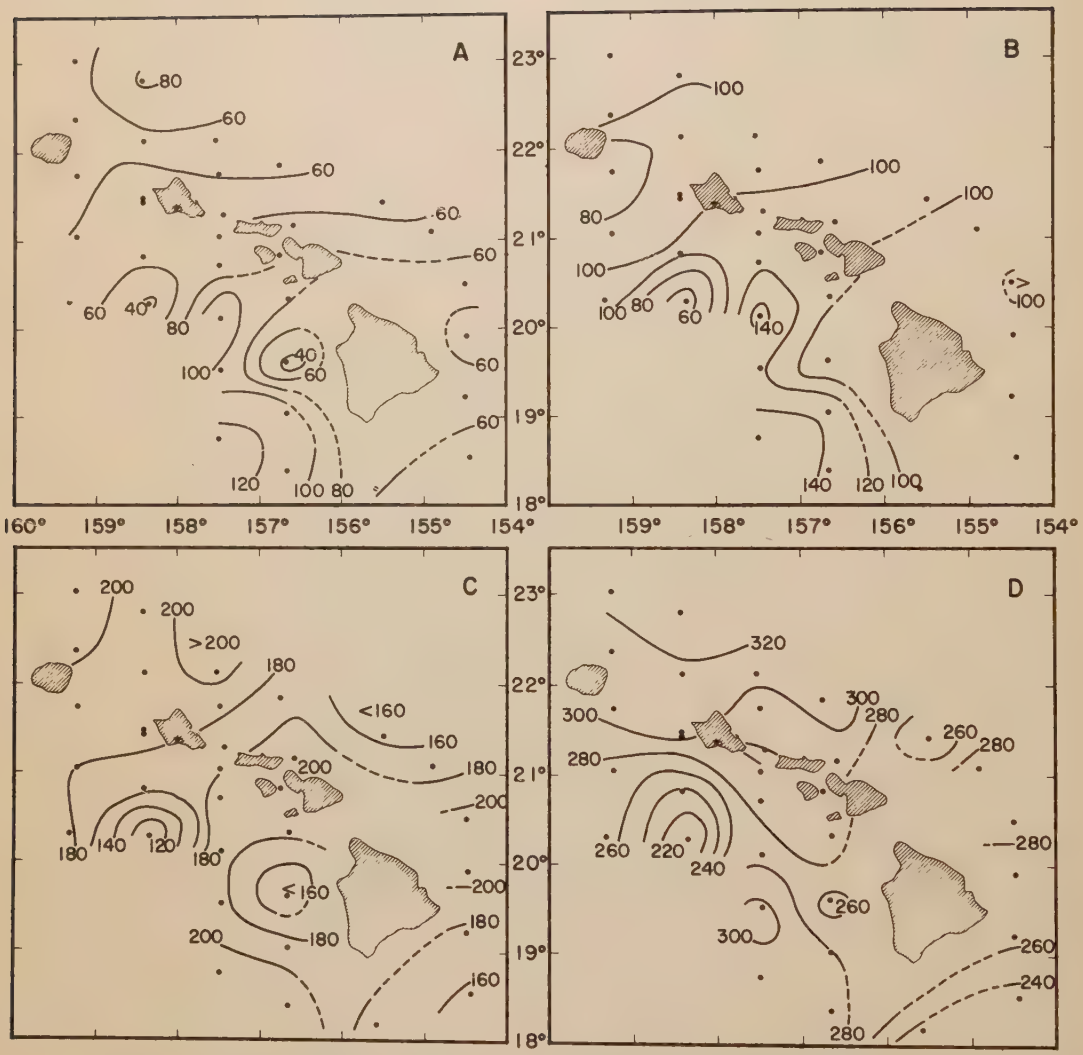

Fig. 18.--H. M. Smith cruise 10. Topography in meters of 23.2, 24.0, 25.0, and 26.0 sigma-t surfaces. Contour interval 20.0 meters. A. 23.2, B. 24.0, C. 25.0, and D. 26.0 sigma-t surfaces.

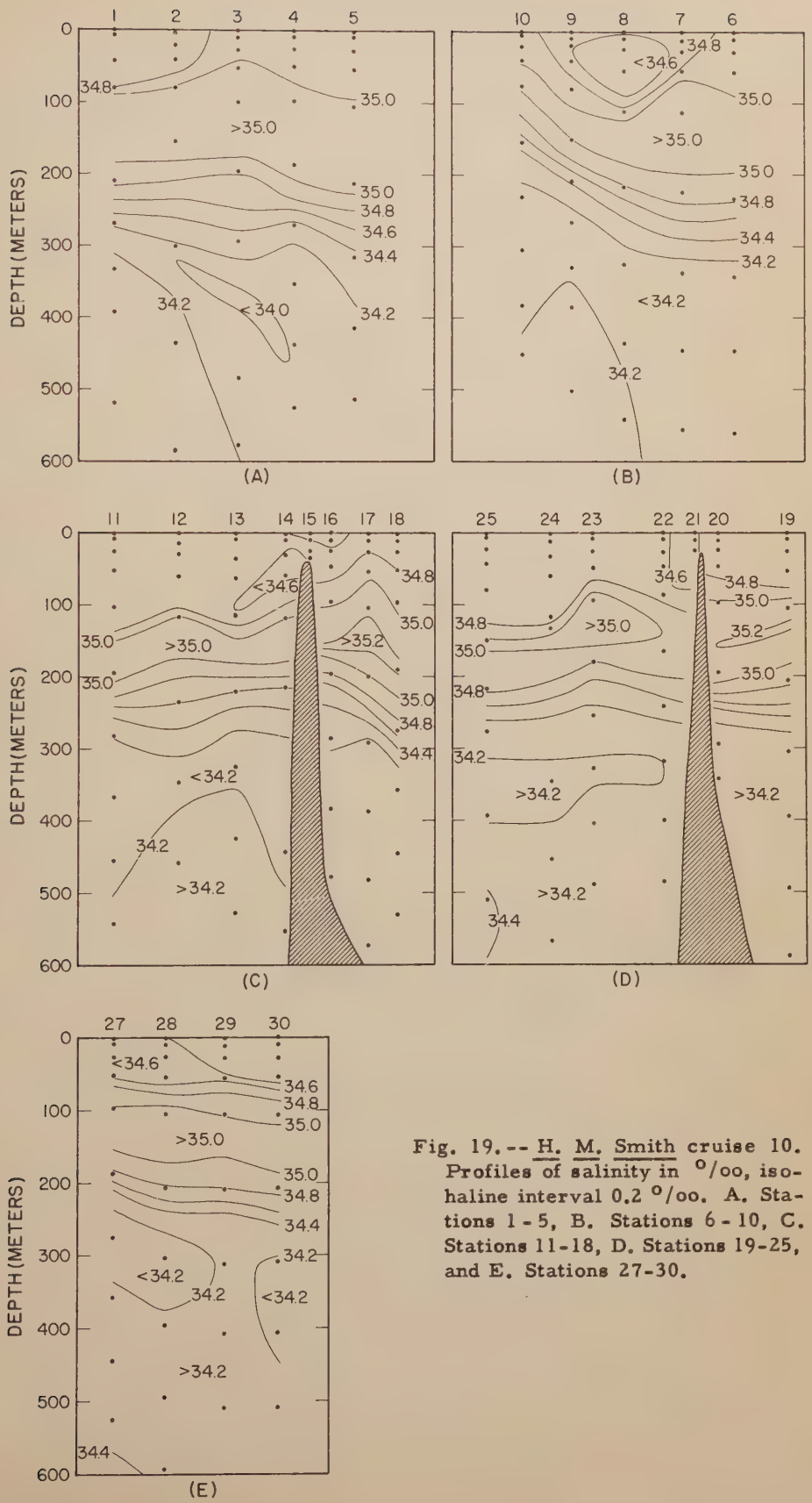

Fig. 19.-- H. M. Smith cruise 10. Profiles of salinity in °/oo, isohaline interval 0.2 °/oo. A. Stations 1 - 5, B. Stations 6 - 10, C. Stations 11-18, D. Stations 19-25, and E. Stations 27-30.

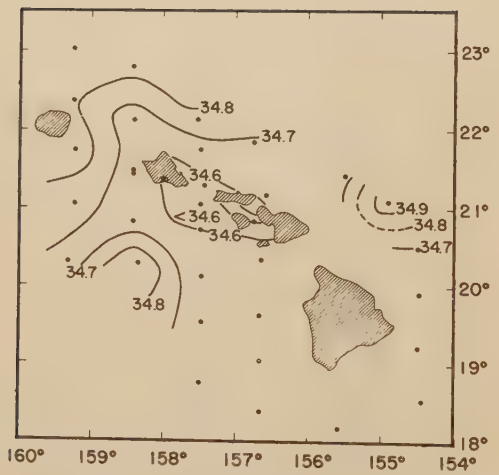

Fig. 20.-- H. M. Smith cruise 10. Surface salinity in °/oo, isohaline interval 0.1 °/oo.

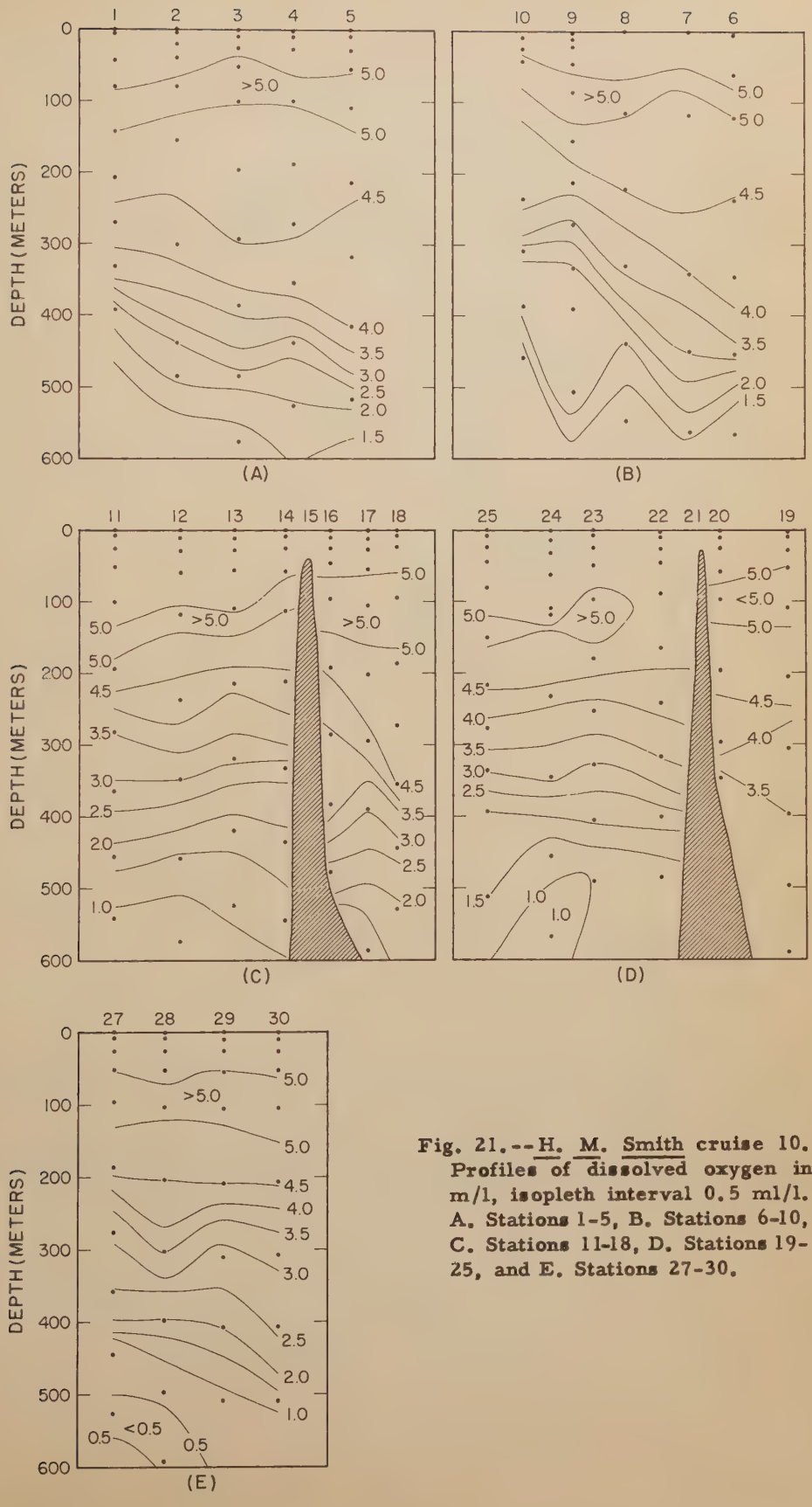

Fig. 21.--H. M. Smith cruise 10. Profiles of dissolved oxygen in m/l, isopleth interval 0.5 ml/l. A. Stations 1-5, B. Stations 6-10, C. Stations 11-18, D. Stations 19-25, and E. Stations 27-30.

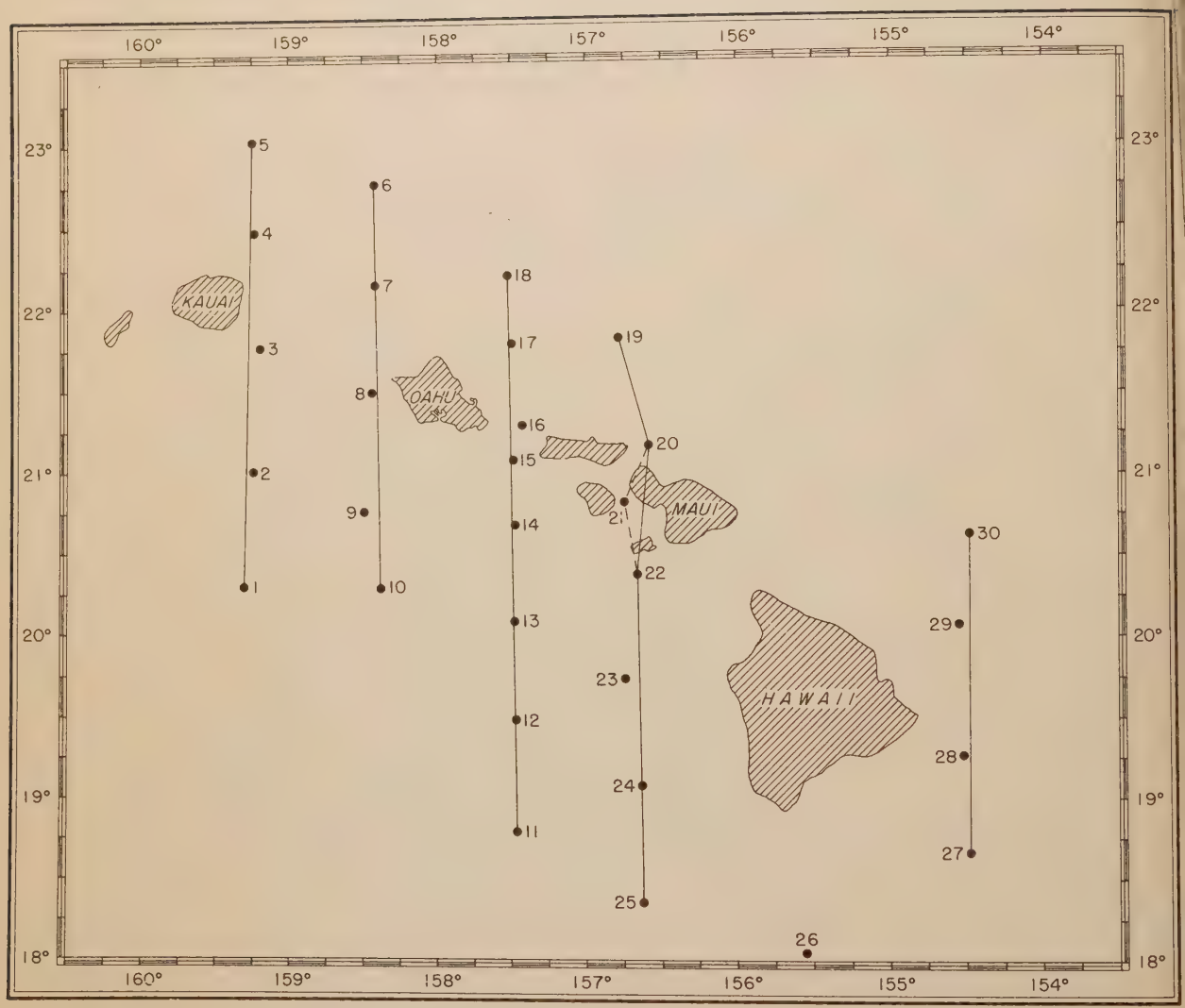

Fig. 22.-- H. M. Smith cruise 12, October 23 to November 2, 1951, station positions. Solid lines indicate lines along which profiles of dynamic heights (dyn. M), BT temperatures (^{o}F), sigma-t, salinity (^{o}/oo), and inorganic phosphate (µg at/l) have been drawn.

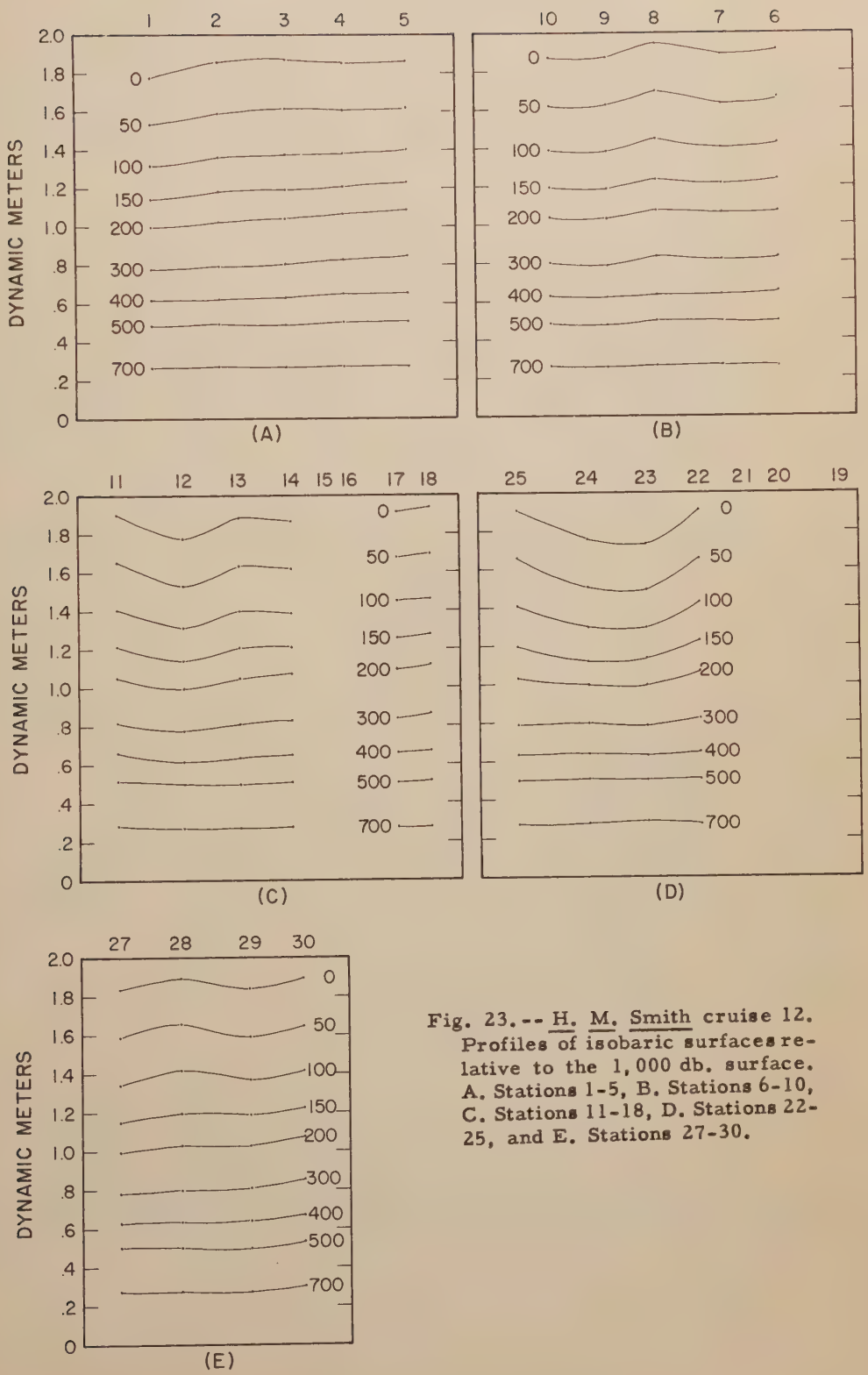

Fig. 23.-- H. M. Smith cruise 12. Profiles of isobaric surfaces relative to the 1,000 db. surface. A. Stations 1-5, B. Stations 6-10, C. Stations 11-18, D. Stations 22-25, and E. Stations 27-30.

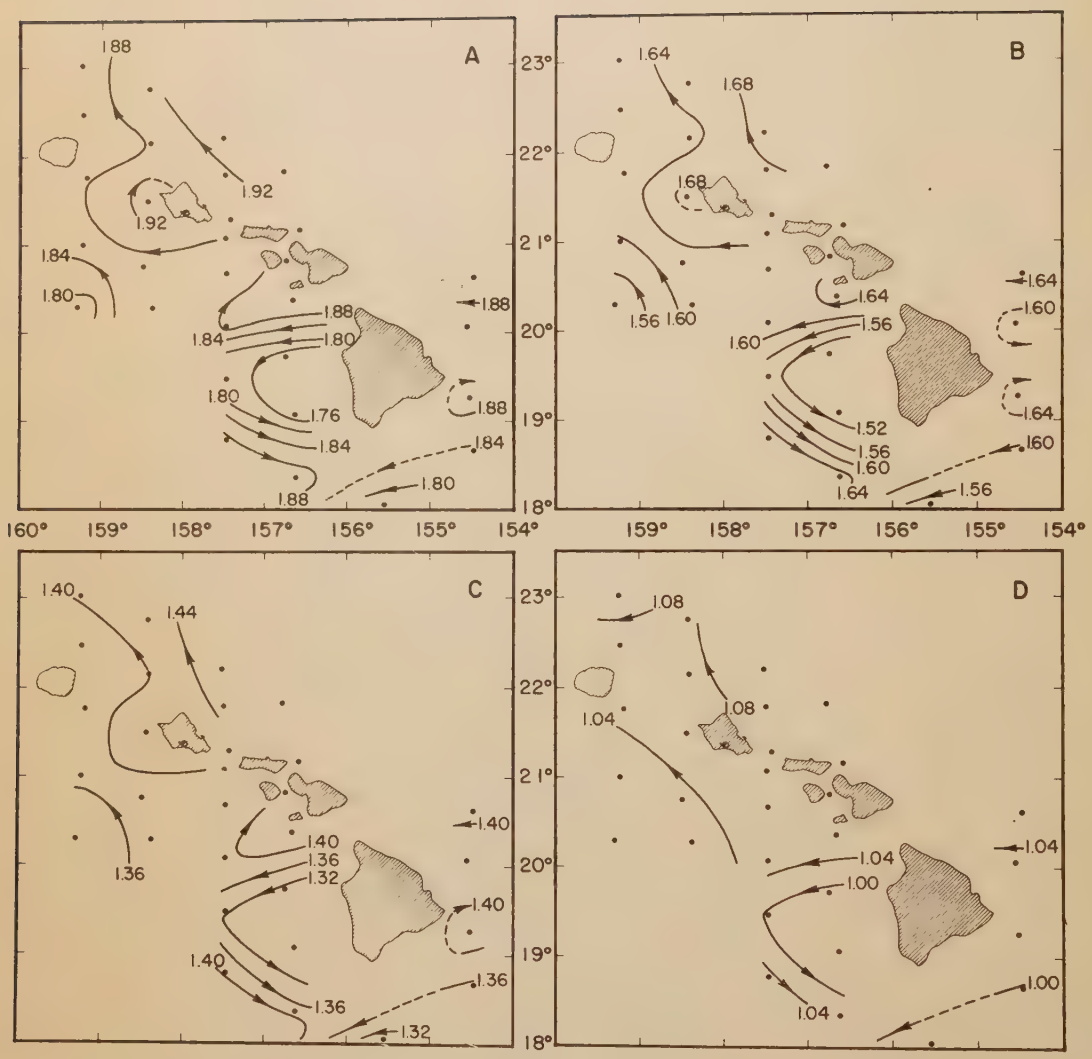

Fig. 24. --H. M. Smith cruise 12. Topography (dyn. M) relative to the 1,000 db. surface, contour interval 0.04 dyn. M. Arrows indicate direction of flow. A. 0 db., B. 50 db., C. 100 db., and D. 200 db. surfaces.

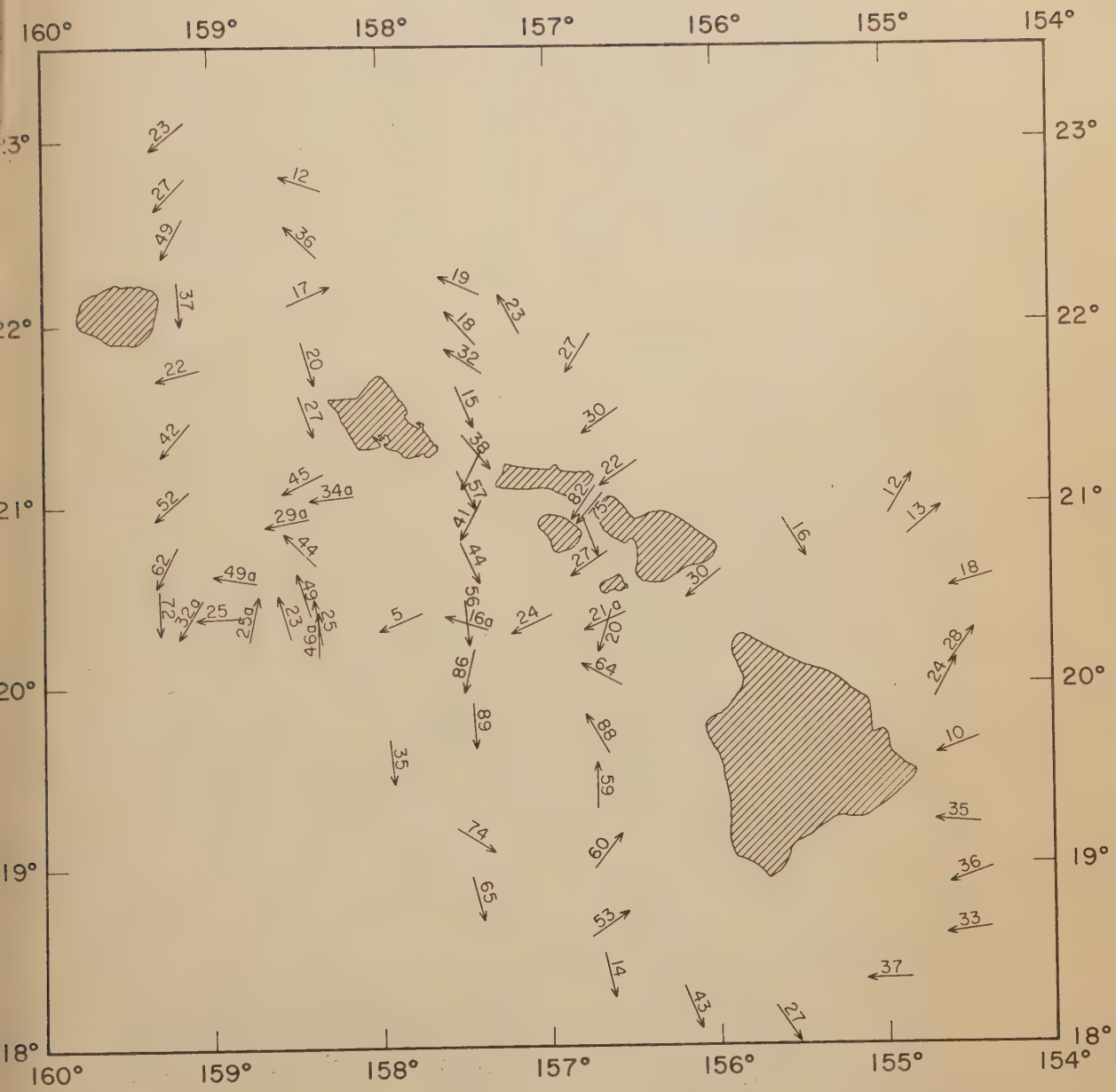

Fig. 25.--H. M. Smith cruise 12. Current vectors computed from GEK measurements, velocities in cm/sec. "a" indicates observations made during the recheck of the area south of Oahu at the end of the cruise.

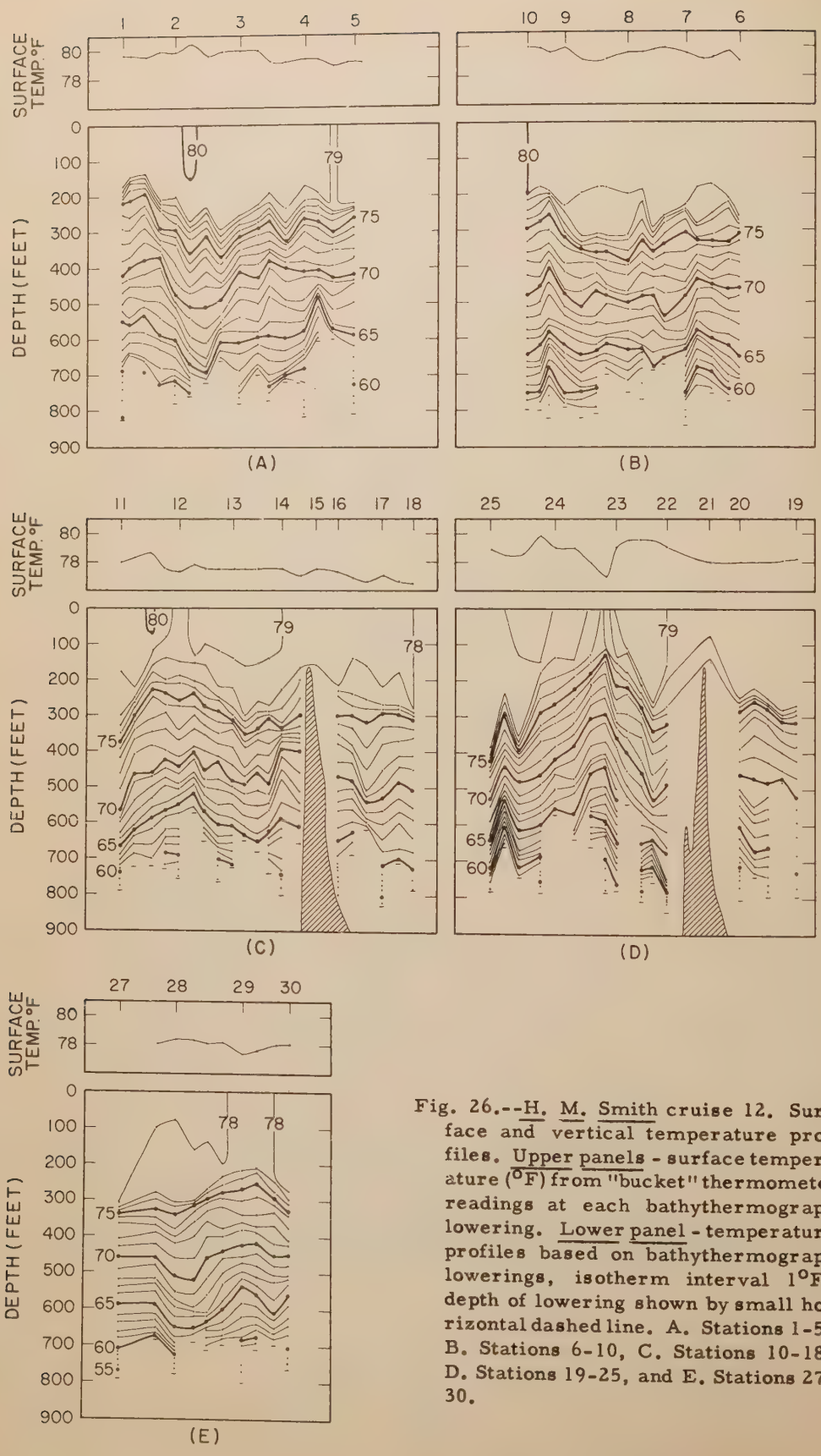

Fig. 26.--H. M. Smith cruise 12. Surface and vertical temperature profiles. Upper panels - surface temperature (^{o}F) from "bucket" thermometer readings at each bathythermograph lowering. Lower panel - temperature profiles based on bathythermograph lowerings, isotherm interval $1^{o}F$, depth of lowering shown by small horizontal dashed line. A. Stations 1-5, B. Stations 6-10, C. Stations 10-18, D. Stations 19-25, and E. Stations 27-30.

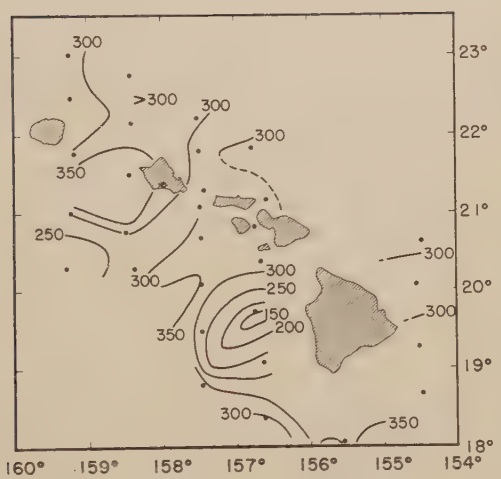

Fig. 27. --H. M. Smith cruise 12. Topography in feet of the 75.0°F isotherm, contour interval 50 feet.

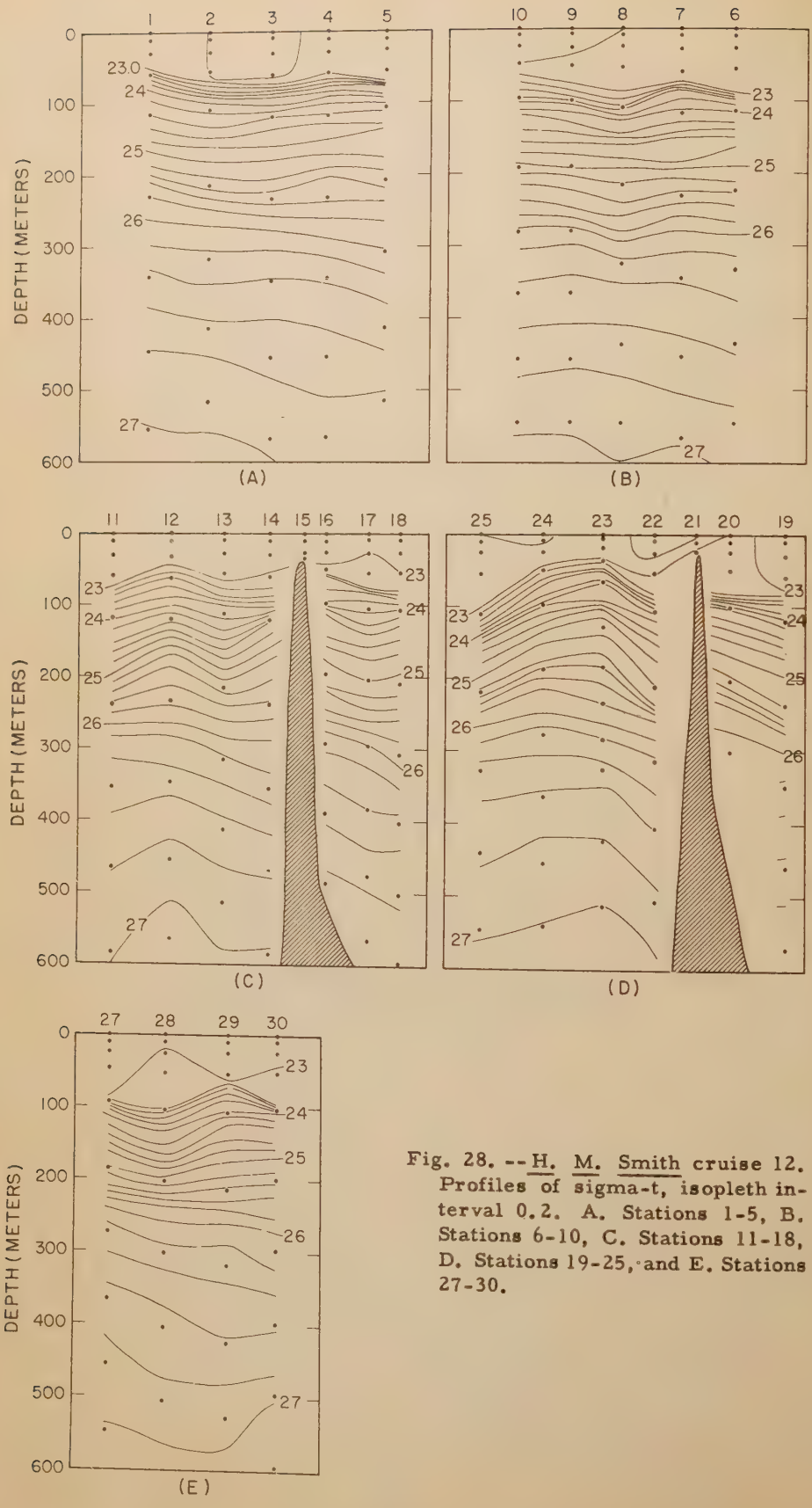

Fig. 28. --H. M. Smith cruise 12. Profiles of sigma-t, isopleth interval 0.2. A. Stations 1-5, B. Stations 6-10, C. Stations 11-18, D. Stations 19-25, and E. Stations 27-30.

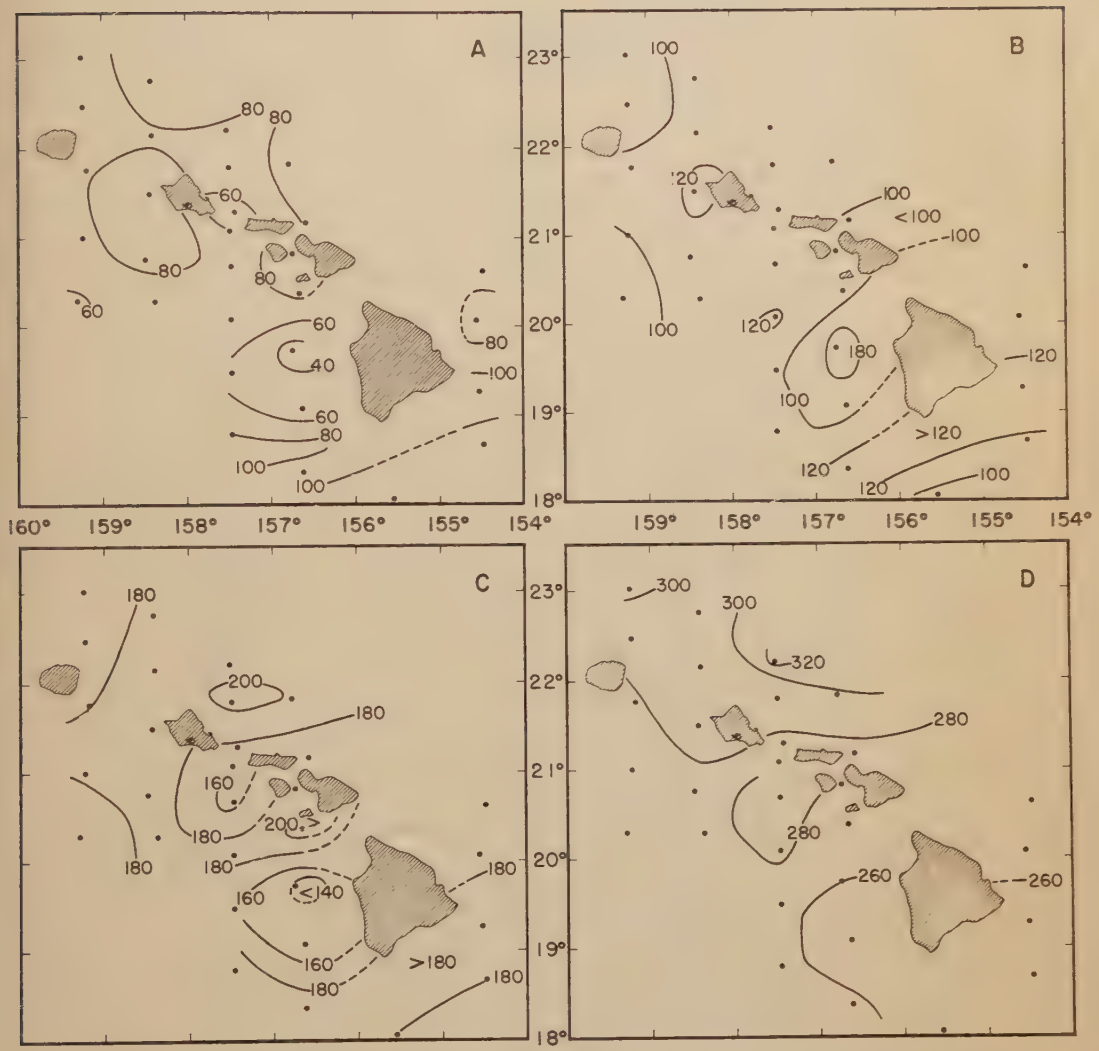

Fig. 29.-- H. M. Smith cruise 12. Topography in meters of the 23.2, 24.0, 25.0, and 26.0 sigma-t surfaces. Contour interval 20 meters. A. 23.2, B. 24.0, C. 25.0, and D. 26.0 surfaces.

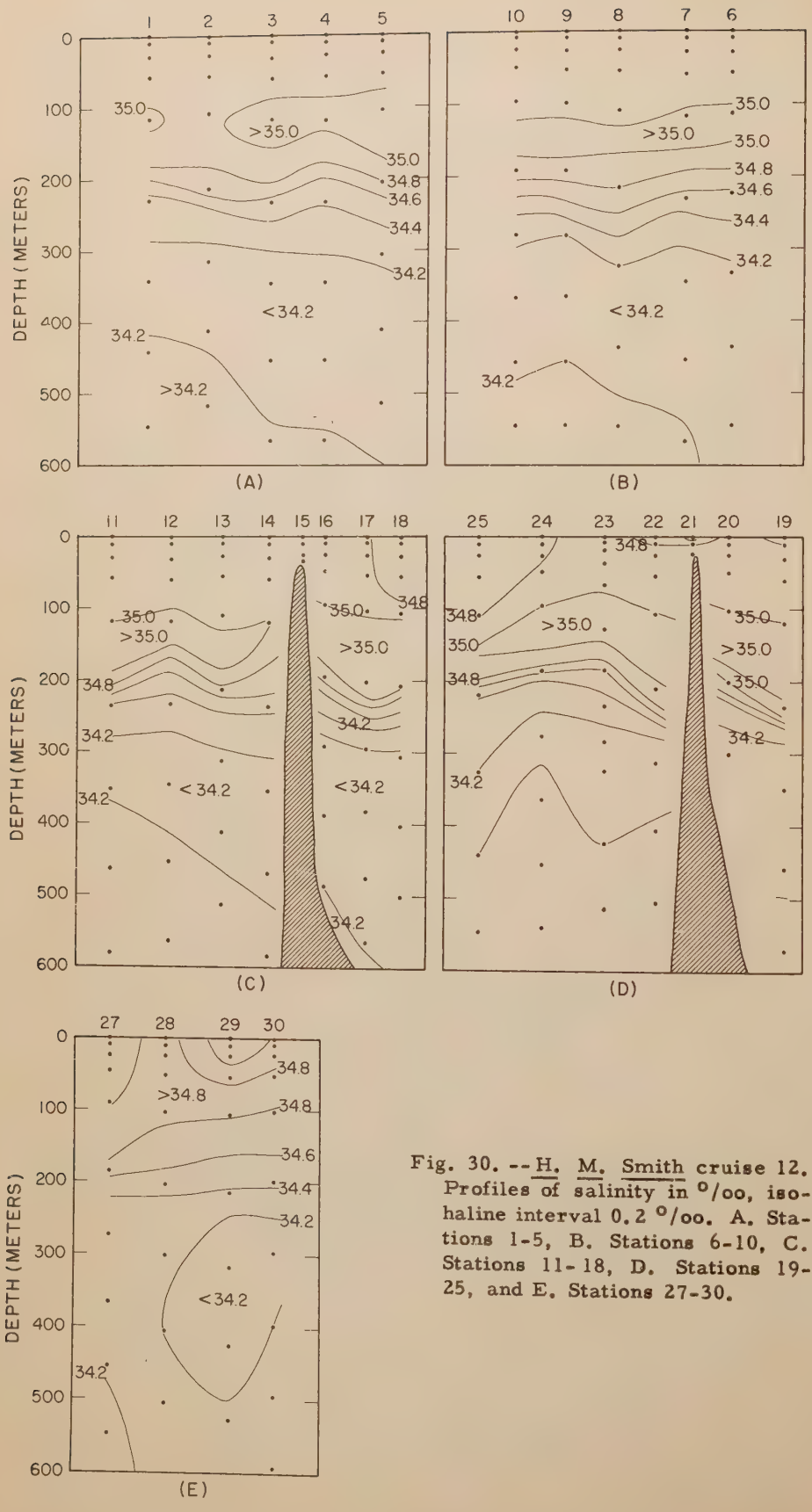

Fig. 30. --H. M. Smith cruise 12. Profiles of salinity in °/oo, isohaline interval 0.2 °/oo. A. Stations 1-5, B. Stations 6-10, C. Stations 11-18, D. Stations 19-25, and E. Stations 27-30.

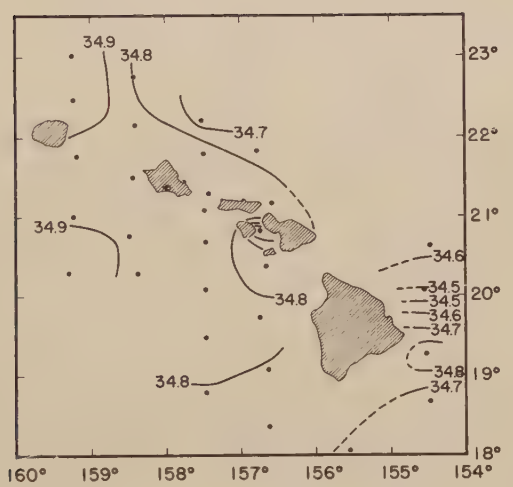

Fig. 31.--H. M. Smith cruise 12. Surface salinity in °/oo, isohaline interval 0.10 °/oo.

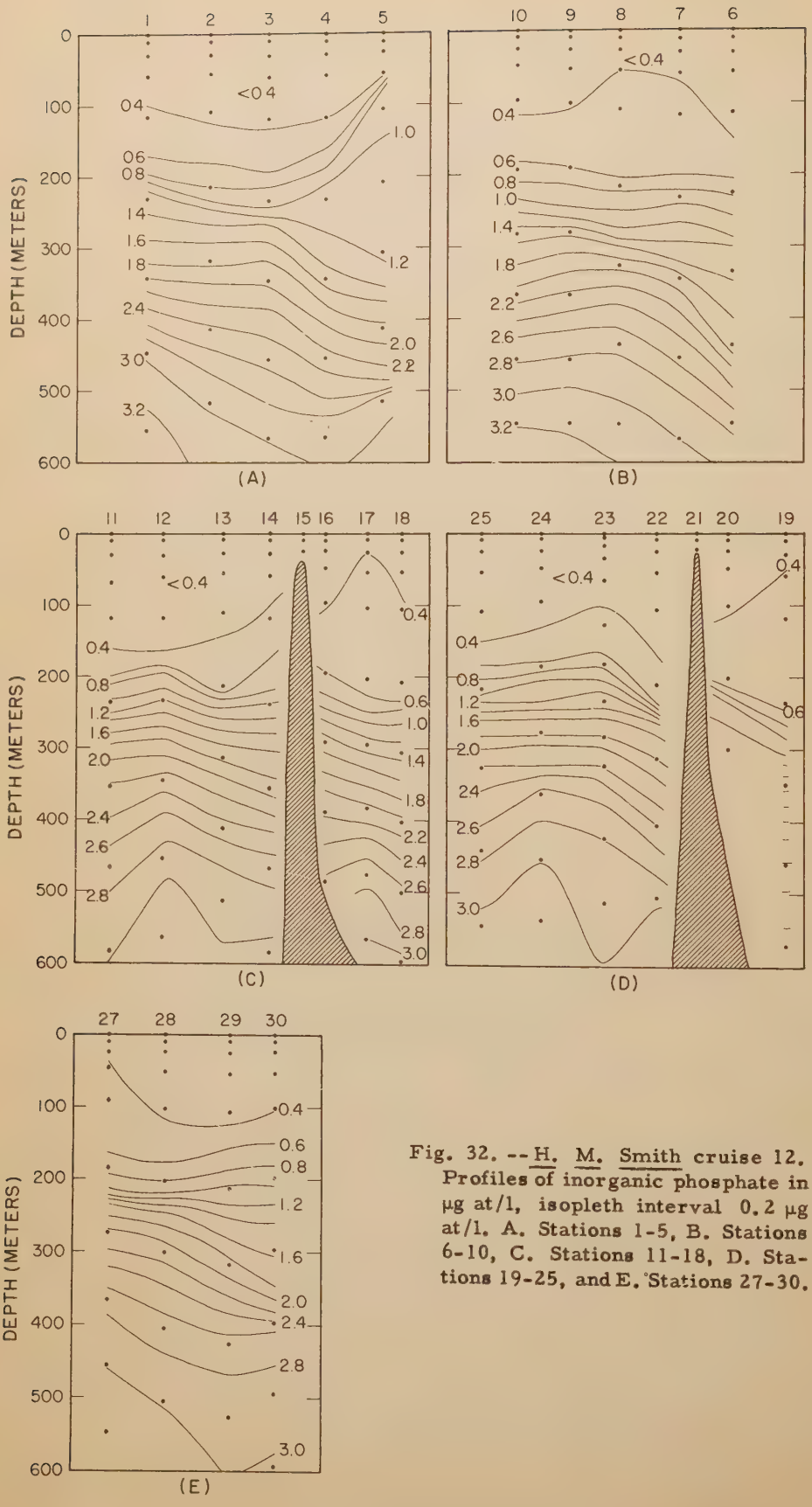

Fig. 32. --H. M. Smith cruise 12. Profiles of inorganic phosphate in µg at/l, isopleth interval 0.2 µg at/l. A. Stations 1-5, B. Stations 6-10, C. Stations 11-18, D. Stations 19-25, and E. Stations 27-30.

Fig. 33.--Cross section of the Windward or High Islands of the Hawaiian Archipelago.

Remarks about the oceanographic data

Weather was recorded according to the ww code as it appears in The U.S. Weather Bureau Circular M, Instructions to Marine Meteorological Observers.

Wind velocity was measured using an anemometer located 30 m. above the sea surface.

In the tabulated data, the horizontal line(s) between depths separates the two or more casts necessary during the particular station.

Whenever there is no doubt concerning data being in error (Nansen bottle pretrip, bottle leakage, etc.), these data are not carried in the tabulations and a footnote is appended. If values are doubtful, but there is no positive evidence of an error, the data are carried with appropriate footnotes.

When the interpolated and calculated values are shown for greater depths than the observed values, they were obtained by extrapolation using the data from adjoining stations as a guide.

STATION 1

M/V Hugh M. Smith: Cruise 1, 18°50'N., 155°49'W., December 17, 1949. Messenger time: 2313 GCT. Weather: scattered clouds, cirrus. Wind: 100°, 4 kt. Sea: 3-5 ft. Wire angle: 42°. Depth of water: 1400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.42		4.84	
18	24.42	34.42	23.10	4.80	
36	24.52	34.70	23.28	4.82	
70	24.41	34.79	23.38	4.84	
133	19.70	34.89	24.77	4.84	
193	16.20	34.55	25.37	4.01	
253	12.09	34.18	25.96	3.88	
374	08.73	34.14	26.51	2.40	
497	06.75	34.11	26.77	1.57	
623	05.94	34.20	26.95	0.86	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.51	34.42	23.05	0.000	1.899
10	24.48	34.42	23.08	0.048	1.851
20	24.45	34.42	23.09	0.096	1.803
30	24.50	34.58	23.20	0.144	1.755
50	24.46	34.74	23.33	0.236	1.663
75	24.42	34.80	23.38	0.350	1.549
100	24.12	34.86	23.52	0.462	1.436
150	18.95	34.82	24.91	0.651	1.248
200	16.05	34.53	25.40	0.796	1.104
250	12.42	34.20	25.91	0.916	0.982
300	10.49	34.16	26.23	1.018	0.881
400	08.24	34.13	26.57	1.188	0.710
500	06.70	34.11	26.78	1.334	0.565
600	06.03	34.18	26.92	1.463	0.436
700	05.69	34.24	27.01	1.581	0.318
800	05.41	34.30	27.09	1.693	0.206
1000	05.03	34.40	27.22	1.899	0.000

STATION 2

M/V Hugh M. Smith: Cruise 1, 18°32'N., 156°15'W., December 18, 1949. Messenger time: 0438 GCT. Weather: scattered clouds, cirrus. Wind: 130°, 4 kt. Sea: 3-5 ft. Wire angle: 45°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.40		4.70	
18	24.66	34.32	22.95	4.80	
36	24.63	34.35	22.98	4.87	
70	22.14	34.70	23.97	5.10	
137	18.98	34.61	24.74	4.98	
204	15.17	34.43	25.52	3.82	
271	10.56	34.22	26.26	3.35	
407	07.50	34.14	26.69	1.85	
545	05.94	34.29	27.02	0.95	
687	05.30	34.33	27.13	0.98	
1052	03.90	34.51	27.43	1.52	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.71	34.40	23.00	0.000	1.764
10	24.68	34.33	22.95	0.049	1.716
20	24.66	34.32	22.95	0.098	1.666
30	24.64	34.34	22.97	0.147	1.617
50	24.58	34.40	23.04	0.245	1.519
75	21.92	34.70	24.03	0.355	1.410
100	21.02	34.68	24.26	0.450	1.314
150	18.47	34.58	24.85	0.623	1.142
200	15.90	34.47	25.38	0.769	0.996
250	11.99	34.28	26.05	0.886	0.878
300	09.67	34.18	26.39	0.980	0.784
400	07.62	34.14	26.67	1.139	0.626
500	06.39	34.24	26.92	1.272	0.493
600	05.65	34.31	27.07	1.387	0.378
700	05.24	34.34	27.15	1.492	0.273
800	04.83	34.38	27.23	1.590	0.175
1000	04.10	34.48	27.38	1.764	0.000

STATION 3

M/V Hugh M. Smith: Cruise 1, 18°16'N., 156°39'W., December 18, 1949. Messenger time: 0915 GCT. Weather: scattered clouds, form not recorded. Wind: 100°, 3 kt. Sea: 3-5 ft. Wire angle: 00°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		35.07		4.87	
25	24.23	35.08	23.65	4.82	
50	24.26	35.05	23.62	4.72	
100	21.01	35.06	24.55	4.62	
199	18.39	34.93	25.14	4.42	
298	10.93	34.14	26.14	3.68	
398	07.72	34.11	26.63	2.23	
597	05.70	34.29	27.05	0.88	
796	04.73	34.44	27.28	1.01	
995	04.10	34.46	27.37	1.16	
1493	02.75	34.52	27.54	1.74	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.30	35.07	23.63	0.000	1.756
10	24.29	35.08	23.64	0.043	1.713
20	24.27	35.08	23.64	0.085	1.671
30	24.27	35.08	23.64	0.128	1.628
50	24.28	35.05	23.62	0.214	1.542
75	22.56	35.08	24.14	0.315	1.441
100	21.03	35.06	24.55	0.406	1.350
150	20.07	35.04	24.79	0.573	1.183
200	18.38	34.93	25.14	0.727	1.029
250	14.45	34.50	25.72	0.859	0.898
300	10.79	34.14	26.16	0.966	0.790
400	07.68	34.11	26.69	1.137	0.619
500	06.54	34.20	26.87	1.274	0.482
600	05.68	34.30	27.06	1.392	0.364
700	05.13	34.40	27.21	1.494	0.262
800	04.68	34.44	27.29	1.586	0.170
1000	04.08	34.46	27.37	1.756	0.000

STATION 4

M/V Hugh M. Smith: Cruise 1, 17°56'N., 157°06'W., December 18, 1949. Messenger time: 1435 GCT. Weather: scattered clouds, form not recorded. Wind: 110°, 3 kt. Sea: 3-5 ft. Wire angle: 05°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		35.09		4.80	
24	24.23	35.06	23.64	4.82	
49	24.28	35.07	23.63	4.82	
98	21.71	35.08	24.38	4.72	
196	18.69	34.95	25.08	4.54	
295	11.00	34.20	26.17	3.66	
394	08.04	34.33 1/	26.76	1.62	
591	05.79	34.35	27.09	0.98	
790	04.90	34.47	27.29	0.96	
988	04.19	34.48	27.38	1.57	
1488	02.82	34.57	27.58	1.88	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.24	35.09	23.66	0.000	1.768
10	24.24	35.07	23.64	0.043	1.725
20	24.23	35.06	23.64	0.085	1.682
30	24.24	35.06	23.64	0.128	1.640
50	24.26	35.07	23.64	0.214	1.554
75	23.75	35.08	23.80	0.319	1.444
100	21.68	35.08	24.39	0.416	1.352
150	20.07	35.03	24.78	0.587	1.181
200	18.62	34.94	25.09	0.742	1.026
250	14.90	34.55	25.67	0.876	0.891
300	10.72	34.18	26.21	0.984	0.784
400	07.90	34.11	26.61	1.154	0.613
500	06.60	34.21	26.87	1.293	0.474
600	05.72	34.37	27.11	1.409	0.359
700	05.22	34.45	27.23	1.508	0.260
800	04.85	34.47	27.30	1.598	0.169
1000	04.16	34.48	27.38	1.768	0.000

1/ Value does not fit the T-S curve.

STATION 5

M/V Hugh M. Smith: Cruise 1, 18°20'N., 157°23'W., December 18, 1949. Messenger time: 1920 GCT. Weather: scattered clouds, cirrostratus. Wind: 120°, 3 kt. Sea: 3-5 ft. Wire angle: 15°. Depth of water: 1800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		35.12		4.82	
24	24.18	35.05	23.65	4.80	
47	24.14	35.03	23.64	4.84	
94	23.22	35.15	24.00	4.86	
186	18.96	34.96	25.02	4.47	
279	11.54	34.19	26.06	3.96	
372	08.30	34.11	26.55	1.16	
557	05.77	34.34	27.08	0.80	
744	05.16	34.45	27.24	0.86	
932	04.34	34.50	27.37	1.18	
1408	03.04	34.56	27.55	1.62	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.16	35.12	23.71	0.000	1.754
10	24.16	35.09	23.68	0.042	1.712
20	24.17	35.06	23.66	0.085	1.670
30	24.16	35.04	23.65	0.127	1.627
50	24.14	35.03	23.64	0.213	1.541
75	24.11	35.10	23.70	0.319	1.435
100	22.85	35.15	24.11	0.420	1.334
150	20.54	35.07	24.69	0.600	1.154
200	18.14	34.89	25.17	0.756	0.998
250	14.13	34.46	25.76	0.886	0.868
300	10.34	34.14	26.24	0.990	0.764
400	07.76	34.11	26.63	1.158	0.596
500	06.27	34.35	27.03	1.288	0.466
600	05.56	34.38	27.14	1.395	0.359
700	05.27	34.43	27.21	1.494	0.260
800	04.98	34.47	27.28	1.586	0.168
1000	04.13	34.51	27.40	1.754	0.000

STATION 6

M/V Hugh M. Smith: Cruise 1, 18°41'N., 156°54'W., December 19, 1949. Messenger time: 0057 GCT. Weather: Rain showers, cloud form not recorded. Wind: 100°, 3 kt. Sea: no observation. Wire angle: 05°. Depth of water: 1400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		35.07		4.78	
25	24.31	35.08	23.63	4.82	
50	23.43	35.13	23.93	4.90	
99	20.54	35.07	24.69		
198	14.28	34.49	25.75	4.28	
297	10.70	34.19	26.22	3.54	
396	08.12	34.19	26.64	2.18	
593	05.95	34.36	27.08	1/	
791	04.82	34.45	27.28	0.94	
989	04.04	34.51	27.41	1.20	
1484	02.76	34.56	27.58	1.74	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.52	35.07	23.56	0.000	1.657
10	24.43	35.07	23.59	0.043	1.614
20	24.39	35.08	23.60	0.086	1.571
30	24.34	35.09	23.63	0.129	1.528
50	23.33	35.13	23.96	0.212	1.445
75	21.63	35.11	24.42	0.306	1.351
100	20.54	35.07	24.69	0.392	1.265
150	18.26	34.90	25.15	0.547	1.110
200	14.20	34.48	25.76	0.677	0.980
250	11.61	34.26	26.11	0.784	0.873
300	10.65	34.19	26.23	0.880	0.777
400	08.02	34.20	26.66	1.047	0.610
500	06.77	34.30	26.92	1.181	0.476
600	05.88	34.37	27.09	1.296	0.361
700	05.33	34.41	27.19	1.398	0.259
800	04.79	34.45	27.29	1.491	0.166
1000	04.01	34.51	27.42	1.657	0.000

1/ Sample spoiled.

STATION 7

M/V Hugh M. Smith: Cruise 1, 18°55'N., 156°36'W., December 19, 1949. Messenger time: first cast 0620 GCT, second cast 0703 GCT. Weather: no observation. Wind: 010°, 2 kt. Sea: no observation. Wire angle: first cast 23°, second cast 45°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.27		4.84	
22	24.78	34.42	22.99	4.78	
45	24.62	34.43	23.04	4.74	
89	21.81	34.90	24.21	5.19	
177	18.06	34.88	25.18	4.54	
266	11.60 1/	34.17	26.04	2.28 3/	
241	11.80 1/	34.17 2/	26.00	3.83	
365	07.77	34.33 2/	26.80	2.25	
493	05.73	34.29	27.05	0.95	
626	05.00	34.43	27.25	1.39	
1128	03.55	34.55	27.49	1.41	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.80	34.27	22.87	0.000	1.683
10	24.80	34.37	22.95	0.050	1.633
20	24.76	34.42	23.00	0.099	1.584
30	24.71	34.42	23.00	0.148	1.535
50	24.59	34.44	23.06	0.244	1.438
75	22.60	34.84	23.95	0.355	1.328
100	21.63	34.90	24.26	0.452	1.231
150	19.37	34.92	24.88	0.623	1.060
200	16.38	34.74	25.48	0.766	0.916
250	11.83	34.19	26.01	0.883	0.800
300	09.90	34.14	26.32	0.979	0.704
400	07.05	34.16	26.77	1.136	0.547
500	05.63	34.30	27.07	1.257	0.426
600	05.07	34.42	27.23	1.357	0.325
700	04.75	34.46	27.30	1.447	0.235
800	04.38	34.50	27.37	1.531	0.152
1000	03.74	34.54	27.47	1.683	0.000

1/ Value does not fit the temperature-depth curve.

2/ Value does not fit the temperature-salinity curve.

3/ Value does not fit the oxygen-temperature curve.

STATION 8

M/V Hugh M. Smith: Cruise 1, 19°15'N., 156°06'W., December 19, 1949. Messenger time: 1235 GCT. Weather: overcast (with breaks), cloud form not recorded. Wind: 280°, slight. Sea: < 1 ft. Wire angle: 07°. Depth of water: 1790 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.84		4.90	
25	24.64	34.83	23.34	4.82	
50	24.68	34.92	23.40	4.80	
99	24.12	35.07	23.68	4.84	
196	17.35	34.63	25.16	4.20	
293	11.18	34.18	26.13	3.74	
390	07.80	34.11	26.62	2.66	
585	05.50	34.32	27.10	0.90	
781	04.60	34.43	27.29	1.08	
977	04.06	34.52	27.42	1.26	
1474	02.80	34.61	27.61	1.76	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.70	34.84	23.33	0.000	1.790
10	24.68	34.83	23.33	0.046	1.745
20	24.66	34.83	23.34	0.091	1.699
30	24.66	34.84	23.35	0.137	1.654
50	24.68	34.92	23.40	0.227	1.563
75	24.52	35.01	23.51	0.339	1.451
100	24.09	35.07	23.69	0.448	1.343
150	19.91	34.87	24.70	0.637	1.153
200	16.89	34.60	25.25	0.790	1.000
250	13.83	34.35	25.74	0.919	0.872
300	10.81	34.17	26.18	1.026	0.765
400	07.63	34.11	26.65	1.195	0.596
500	06.33	34.22	26.91	1.330	0.461
600	05.38	34.33	27.12	1.442	0.348
700	04.87	34.39	27.23	1.540	0.250
800	04.51	34.45	27.32	1.630	0.161
1000	03.98	34.53	27.44	1.790	0.000

STATION 8-A

M/V Hugh M. Smith: Cruise 1, 19°35'N., 156°11'W., December 14, 1949. Messenger time: 2210 GCT. Weather: scattered clouds, stratocumulus. Wind: 240°, 3 kt. Sea: < 1 ft. Wire angle: 22°. Depth of water: 2000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.72		3.08	
23	24.48	34.72	23.31	3.24	
46	24.45	34.74	23.33	3.25	
92	24.62	34.96	23.45	3.15	
184	18.86	34.92	25.01	2.82	
275	12.62	34.28	25.93	2.70	
368	08.54	34.14	26.53	1.86	
552	05.06	34.39	27.21	0.69	
923	04.25	34.45	27.34	0.75	
1390	02.96	34.57	27.57	1.10	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.67	34.72	23.25	0.000	1.807
10	24.59	34.72	23.27	0.046	1.761
20	24.49	34.72	23.30	0.092	1.714
30	24.46	34.72	23.31	0.138	1.669
50	24.45	34.75	23.34	0.230	1.577
75	24.54	34.89	23.42	0.343	1.464
100	24.64	34.96	23.44	0.456	1.351
150	22.20	35.06	24.23	0.663	1.144
200	18.38	34.87	25.10	0.831	0.975
250	14.38	34.42	25.68	0.965	0.841
300	11.26	34.20	26.12	1.075	0.732
400	07.45	34.17	26.72	1.244	0.563
500	05.51	34.36	27.13	1.364	0.442
600	04.90	34.40	27.23	1.461	0.346
700	04.66	34.42	27.28	1.551	0.256
800	04.48	34.43	27.30	1.638	0.168
1000	04.10	34.46	27.37	1.807	0.000

STATION 8-B

M/V Hugh M. Smith: Cruise 1, 19°14'N., 156°07'W., December 15, 1949. Messenger time: 2042 GCT. Weather: clear. Wind: 100°, 1 kt. Sea: 1-3 ft. Wire angle: 10°. Depth of water: 1750 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.65		3.08	
25	24.48	34.62	23.23	3.14	
49	24.48	34.68	23.28	3.19	
98	24.54	34.87	23.40	3.22	
195	16.04	34.58	25.43	2.74	
292	11.40	34.21	26.11	2.44	
390	07.96	34.14	26.63	1.58	
585	05.54	34.29	27.07	0.60	
781	04.70	34.45	27.29	0.66	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.51	34.65	23.25	0.000	1.789
10	24.50	34.63	23.24	0.046	1.743
20	24.49	34.62	23.23	0.093	1.696
30	24.48	34.63	23.24	0.140	1.649
50	24.48	34.69	23.28	0.232	1.557
75	24.73	34.81	23.30	0.348	1.441
100	24.51	34.87	23.41	0.462	1.327
150	18.64	34.80	24.98	0.652	1.137
200	15.82	34.56	25.47	0.793	0.996
250	13.05	34.32	25.88	0.913	0.876
300	11.15	34.20	26.14	1.018	0.772
400	07.71	34.14	26.66	1.188	0.601
500	06.17	34.22	26.94	1.322	0.467
600	05.47	34.30	27.09	1.435	0.354
700	05.05	34.39	27.21	1.536	0.253
800	04.63	34.46	27.30	1.627	0.162
1000	03.98	34.52	27.43	1.789	0.000

STATION 9

M/V Hugh M. Smith: Cruise 1, 19°41'N., 156°20'W., December 19, 1949. Messenger time: 2016 GCT. Weather: scattered clouds, form not recorded. Wind: 310°, 1 kt. Sea: <1 ft. Wire angle: 15°. Depth of water: 1500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.72		4.86	
24	24.50	34.69	23.28	4.84	
48	24.52	34.75	23.32	4.85	
95	24.51	34.86	23.40	4.82	
188	17.26	34.78	25.30	4.20	
281	11.92	34.23	26.03	4.03	
373	07.79	34.11	26.63	2.84	
373	07.93	34.11	26.61		
558	05.60	34.23	27.01	1.04	
744	04.84 1/	34.40	27.24	1.01	
744	04.58 1/	34.40	27.27		
932	03.95 1/	34.49	27.41	1.18	
932	04.15 1/	34.49	27.39		
1409	03.00	34.55	27.55	1.62	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.59	34.72	23.28	0.000	1.811
10	24.52	34.70	23.28	0.046	1.765
20	24.51	34.69	23.28	0.092	1.719
30	24.50	34.70	23.29	0.138	1.673
50	24.50	34.75	23.32	0.230	1.581
75	24.50	34.81	23.37	0.345	1.467
100	24.45	34.87	23.43	0.458	1.353
150	20.23	34.94	24.67	0.655	1.157
200	17.06	34.76	25.33	0.806	1.005
250	13.53	34.37	25.82	0.931	0.880
300	11.12	34.18	26.14	1.037	0.774
400	07.46	34.12	26.68	1.207	0.604
500	06.25	34.18	26.90	1.341	0.470
600	05.35	34.27	27.08	1.457	0.354
700	04.87	34.36	27.21	1.558	0.253
800	04.50	34.43	27.30	1.650	0.162
1000	03.82	34.51	27.43	1.811	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-salinity curve.

STATION 10

M/V Hugh M. Smith: Cruise 1, 19°21'N., 156°46'W., December 20, 1949. Messenger time: first cast 0153 GCT, second cast 0300 GCT. Weather: scattered clouds, form not recorded. Wind: 350°, 2 kt. Sea: <1 ft. Wire angle: first cast 32°, second cast 45°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.40		4.90	
20	24.66	34.38	23.00	4.82	
41	24.66	34.38	23.00	4.86	
82	23.03	34.84	23.82	5.10	
164	19.02	34.93	24.98	4.42	
313	09.92	34.17	26.34	3.48	
473	07.05	34.20	26.80	1.49	
637	05.34	34.45	27.22	1.00	
802	04.76	34.46	27.30	1.26	
1231	03.48	34.53	27.48	1.52	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.89	34.40	22.94	0.000	1.794
10	24.71	34.39	22.99	0.049	1.745
20	24.66	34.38	23.00	0.098	1.696
30	24.66	34.38	23.00	0.147	1.647
50	24.66	34.41	23.02	0.244	1.550
75	24.50	34.80	23.36	0.362	1.432
100	21.59	34.92	24.29	0.466	1.328
150	19.45	34.93	24.87	0.637	1.157
200	17.47	34.81	25.27	0.785	1.009
250	14.28	34.45	25.72	0.914	0.880
300	10.75	34.18	26.20	1.021	0.774
400	08.13	34.17	26.62	1.190	0.604
500	06.76	34.23	26.87	1.329	0.465
600	05.61	34.41	27.16	1.443	0.351
700	05.06	34.45	27.26	1.539	0.255
800	04.74	34.46	27.30	1.628	0.166
1000	04.07	34.50	27.40	1.794	0.000

STATION 11

M/V Hugh M. Smith: Cruise 1, 19°04'N., 157°13'W., December 20, 1949. Messenger time: 0817 GCT. Weather: scattered clouds, form not recorded. Wind: 020°, 2 kt. Sea: < 1 ft. Wire angle: 08°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.96		4.96	
24	23.99	35.13	23.76	4.88	
48	23.89	35.13	23.79	4.82	
96	20.99	35.10	24.59	4.74	
191	17.10	34.73	25.30	4.36	
287	10.96	34.20	26.18	3.73	
383	08.07	34.18	26.64	1.68	
574	05.72	34.31	27.06	0.90	
765	04.66 1/	34.42	27.28	0.88	
765	04.82 1/	34.42	27.26		
957	04.05	34.49	27.40	1.18	
1439	02.81	34.56	27.57	1.67	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.00	34.96	23.63	0.000	1.676
10	24.00	35.08	23.72	0.042	1.633
20	23.99	35.13	23.76	0.084	1.592
30	23.98	35.13	23.76	0.126	1.550
50	23.86	35.13	23.80	0.208	1.467
75	21.76	35.12	24.39	0.305	1.371
100	20.82	35.10	24.63	0.391	1.284
150	18.94	34.93	25.00	0.551	1.124
200	16.83	34.70	25.34	0.695	0.981
250	12.80	34.31	25.92	0.817	0.859
300	10.22	34.18	26.30	0.916	0.759
400	07.78	34.18	26.68	1.079	0.597
500	06.42	34.26	26.93	1.211	0.464
600	05.53	34.34	27.11	1.323	0.352
700	04.98	34.40	27.23	1.422	0.253
800	04.57	34.45	27.31	1.512	0.163
1000	03.92	34.50	27.42	1.676	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-salinity curve.

STATION 12

M/V Hugh M. Smith: Cruise 1, 18°45'N., 157°36'W., December 20, 1949. Messenger time: 1335 GCT. Weather: scattered clouds, form not recorded. Wind: 060°, 2 kt. Sea: <1 ft. Wire angle: 35°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		1/			
20	24.17	35.01	23.62	4.80	
41	24.19	35.05	23.64	4.82	
80	24.06	35.05	23.68	4.82	
157	20.58	35.11	24.71	4.82	
230	14.07	34.35	25.69	4.10	
304	10.04	34.18	26.33	3.66	
451	07.42	34.13	26.70	2.10	
598	05.75	34.32	27.07	1.01	
746	05.12	34.43	27.23	1.06	
1114	03.71	34.51	27.45	1.36	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.16	35.01	23.62	0.000	1.794
10	24.15	35.01	23.63	0.043	1.751
20	24.15	35.01	23.63	0.086	1.708
30	24.15	35.03	23.64	0.128	1.665
50	24.14	35.05	23.66	0.214	1.580
75	24.08	35.05	23.68	0.320	1.473
100	23.91	35.07	23.74	0.426	1.367
150	20.85	35.11	24.64	0.617	1.177
200	18.03	34.84	25.16	0.774	1.020
250	12.56	34.26	25.93	0.900	0.894
300	10.22	34.18	26.30	0.999	0.795
400	08.05	34.13	26.60	1.165	0.629
500	06.85	34.17	26.81	1.308	0.486
600	05.75	34.32	27.07	1.429	0.365
700	05.27	34.41	27.20	1.531	0.263
800	04.92	34.45	27.27	1.625	0.169
1000	04.09	34.50	27.40	1.794	0.000

1/ No surface sample.

STATION 13

M/V Hugh M. Smith: Cruise 1, 19°14'N., 157°46'W., December 20, 1949. Messenger time: 1855 GCT. Weather: scattered clouds, cumulus. Wind: direction not recorded, 1 kt. Sea: < 1 ft. Wire angle: 14°. Depth of water: 1500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.97		5.00	
24	24.56	34.92	23.43	4.80	
47	24.56	34.98	23.48	4.74	
95	24.18	35.10	23.69	4.85	
189	19.30	34.96	24.93	4.26	
283	11.89	34.18	26.00	3.81	
377	08.90	34.14	26.48	3.10	
565	05.98	34.28	27.01	1.01	
754	04.98	34.41	27.23	0.98	
944	04.28	34.50	27.38	1.14	
1419	02.98	34.56	27.56	1.62	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.76	34.97	23.41	0.000	1.857
10	24.67	34.94	23.41	0.045	1.812
20	24.56	34.92	23.43	0.090	1.767
30	24.55	34.93	23.45	0.134	1.723
50	24.53	34.99	23.49	0.223	1.634
75	24.38	35.05	23.59	0.333	1.524
100	24.07	35.11	23.73	0.440	1.417
150	21.08	35.10	24.57	0.632	1.225
200	18.90	34.93	25.01	0.794	1.062
250	16.20	34.62	25.43	0.936	0.920
300	11.13	34.16	26.12	1.052	0.805
400	08.41	34.14	26.56	1.230	0.627
500	06.78	34.18	26.83	1.374	0.483
600	05.66	34.32	27.08	1.493	0.364
700	05.20	34.38	27.18	1.596	0.261
800	04.79	34.44	27.28	1.689	0.167
1000	04.09	34.51	27.41	1.857	0.000

STATION 14

M/V Hugh M. Smith: Cruise 1, 19°26'N., 157°34'W., December 20, 1949. Messenger time: first cast 2255 GCT, second cast 2330 GCT. Weather: scattered clouds, cumulus. Wind: 020°, slight. Sea: < 1 ft. Wire angle: first cast 45°, second cast no observation. Depth of water: 1500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.95		4.86	
18	24.39	34.99	23.54	5.04	
35	24.12	35.11	23.71	4.86	
69	24.08	35.13	23.74	4.70	
136	21.54	35.12	24.45	4.62	
201	19.09	35.01	25.02	4.62	
280	12.32	34.25	25.96	3.52	
401	08.33	35.02 1/	27.26	2.23	
538	06.20	34.22	26.93	1.08	
681	05.06	34.34	27.17	0.90	
1061	03.86	34.51	27.43	1.31	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.59	34.95	23.45	0.000	1.837
10	24.43	34.96	23.51	0.044	1.792
20	24.37	35.00	23.55	0.088	1.749
30	24.19	35.09	23.67	0.131	1.706
50	24.10	35.12	23.72	0.215	1.621
75	24.09	35.13	23.74	0.321	1.516
100	23.94	35.13	23.78	0.425	1.411
150	20.95	35.11	24.61	0.615	1.221
200	19.14	35.01	25.01	0.776	1.060
250	16.40	34.63	25.39	0.920	0.917
300	11.18	34.20	26.14	1.036	0.801
400	08.37	34.13	26.56	1.212	0.624
500	06.62	34.19	26.85	1.355	0.482
600	05.63	34.27	27.04	1.474	0.362
700	04.97	34.36	27.20	1.578	0.258
800	04.58	34.42	27.29	1.671	0.166
1000	03.98	34.50	27.41	1.837	0.000

1/ Value does not fit the T-S curve.

STATION 15

M/V Hugh M. Smith: Cruise 1, 19°36'N., 157°06'W., December 21, 1949. Messenger time: 0555 GCT. Weather: scattered clouds, cumulus. Wind: 320°, 2 kt. Sea: < 1 ft. Wire angle: no observation. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.43		4.82	
25	24.67	34.38	22.99	4.84	
50	24.70	1/		4.80	
99	22.78	34.81	23.87	5.15	
196	18.06	34.80	25.12	4.32	
292	11.03	34.21	26.17	3.52	
387	08.53	34.19	26.58	2.42	
579	05.67	34.30	27.06	1.04	
770	04.57	34.45	27.31	0.88	
962	03.95	34.51	27.42	1.23	
1445	02.80	34.53	27.55	2.00	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.80	34.43	22.99	0.000	1.821
10	24.74	34.39	22.98	0.049	1.772
20	24.70	34.38	22.98	0.098	1.723
30	24.68	34.39	23.00	0.147	1.674
50	24.68	34.50	23.08	0.244	1.577
75	24.68	34.67	23.21	0.363	1.458
100	22.68	34.81	23.90	0.472	1.348
150	20.08	34.92	24.70	0.657	1.164
200	17.99	34.79	25.13	0.813	1.008
250	13.92	34.36	25.73	0.945	0.876
300	10.78	34.20	26.21	1.051	0.770
400	08.27	34.19	26.62	1.221	0.600
500	06.68	34.22	26.87	1.360	0.461
600	05.51	34.32	27.10	1.476	0.345
700	04.90	34.41	27.24	1.575	0.246
800	04.43	34.46	27.33	1.663	0.158
1000	03.80	34.52	27.45	1.821	0.000

1/ Sample lost.

STATION 16

M/V Hugh M. Smith: Cruise 1, 20°07'N., 156°25'W., December 21, 1949. Messenger time: 1312 GCT. Weather: clear. Wind: 330°, 3 kt. Sea: 1-3 ft. Wire angle: 55°. Depth of water: 1000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00		34.60		4.90	
15	24.33	34.53	23.21	4.85	
30	24.32	34.69	23.33	4.78	
56	23.33	35.03	23.88	4.84	
106	21.86	35.17	24.40	4.90	
156	20.32	35.12	24.79	4.59	
206	18.13	34.85	25.15	5.38	
314	10.89	34.20	26.19	3.73	
425	07.56	34.17	26.71	2.26	
544	06.18	34.23	26.94	1.04	
871	04.40	34.43	27.31	1.21	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.34	34.60	23.26	0.000	1.823
10	24.32	34.54	23.22	0.046	1.776
20	24.32	34.54	23.22	0.093	1.730
30	24.30	34.69	23.34	0.139	1.684
50	24.29	35.00	23.58	0.228	1.594
75	24.08	35.08	23.70	0.336	1.487
100	22.50	35.16	24.22	0.436	1.387
150	20.39	35.13	24.77	0.611	1.212
200	18.52	34.91	25.09	0.766	1.057
250	15.62	34.54	25.50	0.905	0.918
300	11.62	34.22	26.07	1.020	0.803
400	07.95	34.17	26.65	1.195	0.628
500	06.61	34.20	26.86	1.332	0.490
600	05.77	34.28	27.03	1.452	0.371
700	05.18	34.35	27.16	1.558	0.265
800	04.68	34.41	27.27	1.653	0.170
1000	04.00	34.48	27.39	1.823	0.000

STATION 1

M/V Hugh M. Smith: Cruise 10, 20°18'N., 159°20'W., July 21, 1951. Messenger time: 1820 GCT. Weather: 02, cloud coverage 6. Wind: 060°, 16 kt. Sea: 5-8 ft. Wire angle: 42°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.90	34.65	22.81	4.65	
08	25.94	34.65	22.81	4.66	
22	25.94	1/		4.70	
42	26.05	34.74	22.84	4.69	
80	25.36	34.79	23.09	4.96	
146	21.18	1/			
210	17.64	34.87	25.28	4.70	
270	11.96	34.23	26.02	4.28	
332	08.79	34.04	26.42	3.77	
393	08.19	34.17	26.62	2.30	
520	06.33	2/			
659	05.37	34.35	27.14	0.96	
823	04.64	2/		1.79	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.93	34.65	22.81	0.000	1.845
10	25.94	34.65	22.80	0.051	1.794
20	25.94	34.68	22.83	0.101	1.744
30	25.98	34.71	22.84	0.151	1.694
50	26.04	34.76	22.86	0.252	1.593
75	25.97	34.79	22.90	0.377	1.468
100	23.30	35.05	23.90	0.490	1.355
150	20.99	35.15	24.63	0.676	1.169
200	18.25	34.93	25.17	0.832	1.013
250	14.10	34.47	25.77	0.961	0.884
300	09.90	34.06	26.25	1.064	0.781
400	08.11	34.18	26.63	1.230	0.615
500	06.62	34.28	26.92	1.365	0.480
600	05.72	34.33	27.08	1.479	0.366
700	05.18	34.37	27.17	1.581	0.264
800	04.72	34.40	27.25	1.676	0.169
1000	03.92	34.46	27.38	1.845	0.000

1/ Sample lost. Bottle tripped accidentally.

2/ Value did not fit the temperature-salinity curve.

STATION 2

M/V Hugh M. Smith: Cruise 10, 21°03'N., 159°14'W., July 22, 1951. Messenger time: 0211 GCT. Weather: not recorded. Wind: 020° 14 kt. Sea: not recorded. Wire angle: 00°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
04	26.60	34.77	22.69	4.75	
20	26.48	34.78	22.74	4.75	
40	26.49	34.77	22.73	4.75	
80	23.60	35.01	23.79	5.16	
155	19.76	35.06	24.89	4.56	
300	10.74	34.18	26.20	4.26	
438	07.02	34.01	26.66	2.64	
586	05.64	34.23	27.01	1.09	
725	05.00	34.34	27.18	0.95	
874	04.40	34.42	27.30	1.06	
1163	03.61	1/			
1454	02.96	34.51	27.52	1.68	
1753	02.42	34.57	27.61	1.96	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.61	34.77	22.69	0.000	1.844
10	26.59	34.77	22.69	0.052	1.792
20	26.48	34.78	22.73	0.103	1.741
30	26.48	34.78	22.73	0.155	1.689
50	26.49	34.78	22.73	0.257	1.587
75	24.02	34.97	23.63	0.375	1.469
100	22.64	35.12	24.14	0.477	1.367
150	19.95	35.07	24.84	0.651	1.193
200	17.83	34.87	25.23	0.801	1.043
250	14.13	34.49	25.78	0.928	0.916
300	10.74	34.18	26.20	1.033	0.811
400	07.73	34.01	26.55	1.205	0.639
500	06.35	34.07	26.79	1.349	0.495
600	05.57	34.24	27.02	1.471	0.373
700	05.11	34.33	27.15	1.577	0.267
800	04.71	34.38	27.23	1.673	0.171
1000	03.94	34.46	27.38	1.844	0.000

1/ Value did not fit the temperature-salinity curve.

STATION 3

M/V Hugh M. Smith: Cruise 10, 21°44'N., 159°13'W., July 22, 1951. Messenger time: 0905 GCT. Weather: 03, cloud coverage not recorded. Wind: 060°, 15 kt. Sea: 3-5 ft. Wire angle: 30°. Depth of water: 1850 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.90	34.88	23.01	4.86	
10	25.86	34.86	22.99	4.82	
27	25.42	34.88	23.15	4.80	
51	23.75	35.02	23.75	5.25	
100	21.88	35.17	24.40	5.02	
197	17.81	34.84	25.22	4.54	
294	12.72	34.27	25.90	4.54	
387	08.82	34.08	26.45	3.71	
485	06.81	33.99	26.67	2.26	
578	05.53	34.14	26.95	1.29	
767	04.54	1/			
958	04.12	34.44	27.35	1.24	
1156	03.53	1/		1.26	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.86	34.88	23.00	0.000	1.832
10	25.86	34.86	22.99	0.049	1.783
20	25.86	34.87	23.00	0.098	1.734
30	25.17	34.89	23.22	0.145	1.687
50	23.77	35.02	23.74	0.234	1.598
75	22.64	35.13	24.15	0.334	1.498
100	21.88	35.17	24.40	0.426	1.406
150	20.49	35.11	24.73	0.597	1.235
200	17.68	34.83	25.23	0.749	1.083
250	15.78	34.60	25.50	0.883	0.949
300	12.34	34.25	25.96	1.000	0.832
400	08.52	34.07	26.48	1.188	0.644
500	06.60	34.00	26.70	1.340	0.492
600	05.34	34.19	27.01	1.467	0.365
700	04.78	34.34	27.19	1.570	0.262
800	04.49	34.39	27.27	1.662	0.170
1000	04.01	34.45	27.36	1.832	0.000

1/ Value did not fit the temperature-salinity curve.

STATION 4

M/V Hugh M. Smith: Cruise 10, 22°22'N., 159°15'W., July 22, 1951. Messenger time: 1635 GCT. Weather: 01, cloud coverage 5. Wind: 040°, 13 kt. Sea: 3-5 ft. Wire angle: 32°. Depth of water: 1250 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.60	34.82	23.04	4.82	
09	25.60	34.83	23.05	4.86	
26	25.62	34.85	23.06	4.84	
50	25.44	34.87	23.13	4.94	
99	23.17	35.08	23.97	5.11	
187	19.56	35.05	24.93	4.55	
271	13.71	34.33	25.75	4.52	
352	10.06	34.06	26.23	4.30	
439	07.57	34.02	26.59	2.85	
525	06.38	34.03	26.76	1.98	
701	04.88	1/			
888	04.24	34.41	27.31	0.99	
1077	03.68	1/			

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.59	34.82	23.04	0.000	1.910
10	25.60	34.83	23.05	0.048	1.862
20	25.61	34.84	23.05	0.097	1.813
30	25.62	34.85	23.05	0.145	1.765
50	25.44	34.87	23.12	0.241	1.669
75	24.06	35.00	23.64	0.354	1.556
100	23.14	35.09	23.98	0.457	1.453
150	21.10	35.19	24.63	0.641	1.269
200	19.32	35.02	24.97	0.802	1.108
250	16.00	34.61	25.46	0.943	0.967
300	12.03	34.19	25.97	1.061	0.849
400	08.50	34.03	26.45	1.249	0.661
500	06.66	34.02	26.71	1.403	0.507
600	05.65	34.13	26.93	1.533	0.377
700	04.90	34.27	27.13	1.644	0.266
800	04.52	34.35	27.23	1.742	0.168
1000	03.91	34.50	27.41	1.910	0.000

1/ Value did not fit the temperature-salinity curve.

STATION 5

M/V Hugh M. Smith: Cruise 10, 23°02'N.; 159°15'W., July 22, 1951. Messenger time: 2311 GCT. Weather: 01, cloud coverage 4. Wind: 040°, 16 kt. Sea: 3-5 ft. Wire angle: 27°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
01	25.90	34.80	22.93	4.87	
09	25.89	34.79	22.93	4.86	
28	25.80	34.85	23.00	4.85	
54	25.11	34.85	23.22	5.05	
108	23.32	35.06	23.91	5.11	
213	19.20	35.07	25.04	4.57	
316	13.14	34.34	25.87	4.42	
414	08.89	34.13	26.48	4.04	
516	06.83	34.02	26.69	2.23	
615	05.52	34.12	26.94	1.08	
818	04.52	1/			
1020	03.86	34.59	27.50	1.24	
1228	03.38	34.56	27.52	2.99	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.91	34.80	22.93	0.000	1.974
10	25.88	34.79	22.93	0.049	1.925
20	25.86	34.84	22.97	0.099	1.875
30	25.79	34.85	23.00	0.148	1.826
50	25.73	34.85	23.02	0.245	1.729
75	24.53	34.90	23.42	0.362	1.612
100	23.56	35.03	23.81	0.470	1.504
150	21.90	35.18	24.40	0.663	1.311
200	19.80	35.12	24.92	0.831	1.143
250	17.06	34.81	25.37	0.976	0.998
300	14.00	34.43	25.76	1.101	0.873
400	09.28	34.15	26.42	1.301	0.673
500	07.10	34.02	26.65	1.459	0.515
600	05.72	34.09	26.89	1.595	0.379
700	05.00	34.24	27.09	1.710	0.264
800	04.61	34.35	27.22	1.809	0.165
1000	03.96	34.57	27.47	1.974	0.000

1/ Value did not fit the temperature-salinity curve.

STATION 6

M. V Hugh M. Smith: Cruise 10, 22°48'N., 158°25'W., July 23, 1951. Messenger time: 0738 GCT. Weather: not recorded. Wind: not recorded. Sea: not recorded. Wire angle: 14°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.70	34.86	23.03	4.87	
10	25.74	34.87	23.04	4.88	
30	25.73	34.85	23.03	4.88	
58	25.73	34.87	23.04	4.90	
118	21.94	1/		4.99	
232	17.84	34.86	25.22	4.50	
342	11.26	34.10	26.05	4.45	
448	07.68	34.03	26.58	3.28	
561	06.36	34.15	26.86	1.35	
669	05.10	34.24	27.08	0.84	
892	04.43	34.43	27.31	1.22	
1110	03.75	34.47	27.41	1.33	
1321	03.26	34.47	27.46	1.51	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.73	34.86	23.03	0.000	1.953
10	25.74	34.87	23.03	0.048	1.905
20	25.74	34.86	23.02	0.097	1.856
30	25.73	34.85	23.02	0.145	1.808
50	25.73	34.86	23.03	0.243	1.710
75	25.73	34.87	23.04	0.364	1.589
100	23.16	35.07	23.96	0.475	1.478
150	20.72	35.17	24.71	0.657	1.296
200	19.03	35.01	25.04	0.814	1.139
250	17.13	34.76	25.31	0.958	0.995
300	14.22	34.38	25.68	1.086	0.867
400	08.82	34.04	26.41	1.291	0.662
500	06.78	34.11	26.76	1.444	0.509
600	05.64	34.19	26.97	1.570	0.383
700	04.97	34.26	27.11	1.680	0.273
800	04.69	34.36	27.22	1.778	0.175
1000	04.11	34.46	27.36	1.953	0.000

1/ Sample lost.

STATION 7

M/V Hugh M. Smith: Cruise 10, 22°08'N., 158°24'W., July 23, 1951. Messenger time: 1355 GCT. Weather: 02, cloud coverage 8. Wind: not recorded. Sea: not recorded. Wire angle: 21°. Depth of water: 2700 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
01	25.80	34.65	22.85	4.85	
11	25.86	34.66	22.84	4.85	
29	25.86	34.65	22.84	4.84	
57	25.02	34.94	23.31	5.09	
114	22.26	35.15	24.28	4.81	
226	18.09	34.88	25.18	4.63	
339	10.71	34.14	26.18	3.82	
446	07.85	34.04	26.56	3.15	
559	05.90	34.08	26.86	1.70	
667	04.93	34.19	27.06	0.84	
890	04.16	34.44	27.35	1.41	
1105	03.66	34.47	27.42	1.35	
1316	03.12	1/		1.51	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.83	34.65	22.84	0.000	1.923
10	25.86	34.66	22.84	0.050	1.873
20	25.86	34.66	22.84	0.101	1.822
30	25.86	34.65	22.83	0.151	1.772
50	25.54	34.82	23.06	0.250	1.673
75	24.00	35.04	23.69	0.363	1.560
100	22.93	35.13	24.07	0.465	1.458
150	20.54	35.13	24.73	0.644	1.279
200	18.91	34.98	25.04	0.800	1.123
250	17.00	34.75	25.34	0.943	0.980
300	13.22	34.30	25.82	1.068	0.855
400	08.84	34.09	26.45	1.264	0.659
500	06.86	34.03	26.69	1.418	0.505
600	05.48	34.12	26.94	1.549	0.374
700	04.79	34.23	27.11	1.660	0.263
800	04.41	34.39	27.27	1.756	0.167
1000	03.89	34.46	27.39	1.923	0.000

1/ Value did not fit the temperature-salinity curve.

STATION 8

M/V Hugh M. Smith: Cruise 10, 21°29'N., 158°25'W., July 23, 1951. Messenger time: 2044 GCT. Weather: 01, cloud coverage 9. Wind: not recorded. Sea: < 1 ft. Wire angle: 02°. Depth of water: 1350 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	34.64	22.71	4.80	
10	26.06	34.57	22.71	4.78	
25	26.00	34.58	22.74	4.82	
56	24.98	34.42	22.93	4.99	
111	22.83	34.91	23.94	5.06	
219	17.26	34.77	25.29	4.51	
327	10.56	34.12	26.19	4.27	
437	07.91 1/	34.17	26.65	2.09	
437	07.97 1/	34.17	26.65		
543	06.55	34.22	26.89	1.24	
647	05.51	34.27	27.06	1.05	
855	04.48	34.40	27.28	1.34	
1065	03.88	34.51	27.43	1.33	
1267	03.38	34.50	27.47	2.92	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.23	34.64	22.71	0.000	1.935
10	26.06	34.57	22.71	0.052	1.883
20	26.04	34.58	22.72	0.103	1.832
30	25.99	34.57	22.73	0.154	1.781
50	25.12	34.44	22.90	0.256	1.679
75	24.47	34.48	23.12	0.378	1.557
100	23.52	34.70	23.57	0.492	1.443
150	21.45	35.04	24.42	0.690	1.245
200	18.43	34.91	25.11	0.853	1.082
250	15.07	34.49	25.58	0.988	0.947
300	11.91	34.20	26.00	1.102	0.833
400	08.64	34.14	26.52	1.286	0.649
500	07.04	34.20	26.80	1.432	0.503
600	05.95	34.25	26.98	1.556	0.379
700	05.21	34.30	27.11	1.666	0.269
800	04.71	34.37	27.23	1.764	0.171
1000	03.99	34.49	27.40	1.935	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-salinity curve.

STATION 8-A

M/V Hugh M. Smith: Cruise 10, 21°26'N., 158°25'W., July 19, 1951. Messenger time: 2333 GCT. Weather: 02, cloud coverage 4. Wind: 040°, 14 kt. Sea: 1-3 ft. Wire angle: 07°. Depth of water: 1300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	34.78	22.84	5.00	
10	26.14	34.80	22.86	4.84	
30	26.08	1/		4.86	
61	24.36	34.89	23.47	5.09	
118	22.12	1/		4.97	
235	17.30	1/			
350	09.98	34.12	26.29	4.24	
461	07.42	34.16	26.72	1.83	
578	05.78	34.25	27.01	1.16	
690	05.05	1/		1.22	
919	04.25	2/			
1141	03.60	34.53	27.47	1.33	
1353	03.16	2/			

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.17	34.78	22.83	0.000	1.877
10	26.14	34.80	22.86	0.050	1.827
20	26.11	34.81	22.87	0.100	1.777
30	26.08	34.82	22.89	0.150	1.727
50	25.15	34.83	23.18	0.247	1.630
75	23.62	34.98	23.75	0.358	1.519
100	22.46	35.13	24.20	0.458	1.419
150	20.67	35.13	24.70	0.634	1.243
200	18.86	34.96	25.04	0.792	1.085
250	16.59	34.71	25.40	0.933	0.944
300	13.05	34.35	25.89	1.054	0.823
400	08.59	34.13	26.52	1.243	0.634
500	06.83	34.19	26.82	1.388	0.489
600	05.60	34.27	27.04	1.508	0.369
700	05.02	34.33	27.16	1.612	0.265
800	04.63	34.38	27.24	1.708	0.169
1000	04.01	34.49	27.40	1.877	0.000

1/ Sample lost. Nansen bottle leaked.

2/ Value did not fit the temperature-salinity curve.

STATION 9

M/V Hugh M. Smith: Cruise 10, 20°50'N., 158°25'W., July 23, 1951. Messenger time: 0850 GCT. Weather: not recorded. Wind: direction not recorded, 22 kt. Sea: not recorded. Wire angle: 58°. Depth of water: 2350 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	34.63	22.70	4.83	
10	26.26	34.60	22.67	4.79	
20	26.24	34.60	22.68	4.79	
42	25.90	34.75	22.90	4.92	
81	24.22	34.92	23.54	5.18	
151	20.02	35.00	24.78	4.86	
210	14.66	34.42	25.62	4.17	
269	10.36	34.17	26.26	3.42	
330	08.78	34.19	26.54	2.43	
387	07.88	34.23	26.71	2.02	
503	06.42	34.37	27.02	2.29	
617	05.72	34.35	27.10	0.86	
775	05.08	34.44	27.25	1/	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.24	34.63	22.70	0.000	1.777
10	26.26	34.60	22.67	0.052	1.725
20	26.24	34.60	22.67	0.104	1.673
30	26.16	34.63	22.72	0.155	1.622
50	25.80	34.77	22.94	0.256	1.521
75	24.47	34.90	23.44	0.374	1.403
100	23.16	34.98	23.89	0.481	1.296
150	20.40	35.01	24.68	0.665	1.112
200	15.71	34.55	25.48	0.813	0.964
250	11.30	34.19	26.11	0.926	0.851
300	09.42	34.17	26.42	1.017	0.760
400	07.71	34.24	26.74	1.170	0.607
500	06.48	34.36	27.00	1.295	0.482
600	05.81	34.34	27.07	1.405	0.372
700	05.34	34.39	27.17	1.508	0.269
800	05.00	34.45	27.26	1.603	0.174
1000	04.50	34.49	27.34	1.777	0.000

1/ Sample spoiled.

STATION 10

M/V Hugh M. Smith: Cruise 10, 20°17'N., 158°21'W., July 24, 1951. Messenger time: 1733 GCT. Weather: not recorded. Wind: 060°, 12 kt. Sea: not recorded. Wire angle: 42°. Depth of water: 2520 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.30	34.88	22.88	5.03	
07	26.26	34.92	22.91	4.81	
21	26.28	34.92	22.90	4.85	
41	24.10	34.97	23.61	5.16	
79	20.50	35.01	24.65	4.97	
156	14.84	34.48	25.63	4.15	
233	10.64	34.16	26.21	4.12	
307	08.65	34.14	26.52	2.62	
383	07.28	34.17	26.75	2.09	
454	06.55	34.22	26.89	1.18	
608	05.56	34.39	27.15	1.19	
776	04.94	34.41	27.24	1.01	
962	04.21	34.44	27.34	1.22	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.26	34.88	22.88	0.000	1.586
10	26.26	34.92	22.91	0.050	1.536
20	26.28	34.92	22.90	0.099	1.487
30	26.28	34.93	22.91	0.149	1.437
50	22.56	35.01	24.08	0.237	1.349
75	20.79	35.02	24.58	0.328	1.258
100	19.01	34.93	24.98	0.408	1.178
150	15.30	34.54	25.57	0.545	1.041
200	12.07	34.23	25.99	0.658	0.928
250	10.03	34.16	26.31	0.754	0.832
300	08.80	34.15	26.50	0.838	0.748
400	07.08	34.19	26.79	0.984	0.602
500	06.26	34.26	26.95	1.110	0.476
600	05.63	34.39	27.13	1.219	0.367
700	05.20	34.40	27.19	1.317	0.269
800	04.84	34.41	27.24	1.411	0.175
1000	04.14	34.44	27.34	1.586	0.000

STATION 11

M/V Hugh M. Smith: Cruise 10, 18°45'N., 157°30'W., July 25, 1951. Messenger time: 0646 GCT. Weather: 01, cloud coverage not recorded. Wind: 070°, 16 kt. Sea: 1-3 ft. Wire angle: 32°. Depth of water: 2425 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.90	34.61	22.80	4.86	
09	25.86	34.61	22.80	4.85	
27	25.88	34.61	22.80	4.84	
51	25.72	34.59	22.83	4.87	
101	25.48	34.65	22.95	4.94	
194	20.76	35.11	24.66	4.88	
282	12.24	34.21	25.95	3.52	
367	09.01 1/	34.14	26.46	2.79	
367	09.07 1/	34.14	26.45		
456	07.25	34.14	26.73	1.77	
541	06.46	34.28	26.95	0.93	
719	05.44	34.46	27.22	1.03	
901	04.48	34.50	27.36	1.04	
1090	04.04	2/		0.92	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.86	34.61	22.80	0.000	1.976
10	25.86	34.61	22.80	0.051	1.925
20	25.87	34.61	22.80	0.101	1.875
30	25.88	34.61	22.79	0.152	1.824
50	25.75	34.59	22.82	0.253	1.723
75	25.64	34.60	22.86	0.380	1.596
100	25.49	34.65	22.94	0.505	1.471
150	23.45	35.01	23.83	0.732	1.244
200	20.24	35.06	24.76	0.917	1.059
250	15.13	34.50	25.57	1.061	0.915
300	11.28	34.18	26.10	1.173	0.803
400	08.36	34.14	26.56	1.350	0.626
500	06.81	34.20	26.83	1.492	0.484
600	06.11	34.35	27.04	1.612	0.364
700	05.58	34.44	27.18	1.716	0.260
800	05.02	34.49	27.29	1.809	0.167
1000	04.14	34.50	27.39	1.976	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-salinity curve.

2/ Value did not fit the temperature-salinity curve.

STATION 12

M/V Hugh M. Smith: Cruise 10, 19°32'N., 157°28'W., July 25, 1951. Messenger time: 1435 GCT. Weather: 03, cloud coverage 10. Wind: 240°, 4 kt. Sea: 1-3 ft. Wire angle: 11°. Depth of water: 2360 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.00	34.66	22.79	4.84	
11	25.95	34.64	22.80	4.85	
29	25.84	34.65	22.84	4.86	
60	25.37	34.67	23.00	4.86	
118	23.25	35.04	23.91	5.15	
235	16.36	34.61	25.38	4.35	
349	09.76	34.17	26.36	2.99	
459	07.86	34.29	26.76	1.34	
574	06.34	34.27	26.96	0.74	
683	05.90	34.40	27.11	0.70	
909	04.71	34.50	27.33	1.14	
1129	03.97	34.51	27.42	1.16	
1343	03.40	34.51	27.48	1.51	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.01	34.66	22.79	0.000	1.944
10	25.96	34.64	22.79	0.051	1.893
20	25.91	34.64	22.81	0.101	1.843
30	25.84	34.65	22.84	0.152	1.792
50	25.56	34.66	22.93	0.252	1.692
75	25.25	34.69	23.05	0.374	1.570
100	24.83	34.77	23.24	0.494	1.450
150	21.32	35.12	24.51	0.698	1.246
200	17.85	34.80	25.17	0.856	1.088
250	15.62	34.53	25.49	0.992	0.952
300	12.44	34.24	25.93	1.111	0.833
400	08.76	34.23	26.57	1.296	0.648
500	07.30	34.27	26.82	1.438	0.506
600	06.22	34.30	26.99	1.562	0.382
700	05.83	34.41	27.12	1.671	0.273
800	05.31	34.47	27.24	1.770	0.174
1000	04.34	34.50	27.37	1.944	0.000

STATION 13

M/V Hugh M. Smith: Cruise 10, 20°07'N., 157°28'W., July 25, 1951. Messenger time: 2014 GCT. Weather: 01, cloud coverage 5. Wind: 040°, 19 kt. Sea: 1-3 ft. Wire angle: 31°. Depth of water: 2260 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
01	25.90	34.67	22.85	4.82	
11	25.88	34.64	22.82	4.86	
29	25.88	34.65	22.83	4.83	
56	25.86	34.64	22.82	4.84	
110	24.90	34.60	23.09	4.97	
215	16.83	34.63	25.29	4.15	
320	10.08	34.17	26.31	3.14	
420	08.37	34.25	26.65	1.71	
524	06.79	34.22	26.86	1.08	
625	06.19	34.35	27.04	0.70	
833	04.88	34.48	27.30	1.27	
1041	04.12	34.49	27.39	1.38	
1247	03.52	34.51	27.47	1.42	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.87	34.68	22.85	0.000	1.939
10	25.88	34.64	22.82	0.050	1.889
20	25.88	34.64	22.82	0.101	1.838
30	25.88	34.65	22.82	0.151	1.788
50	25.86	34.65	22.83	0.252	1.687
75	25.84	34.63	22.82	0.379	1.560
100	25.22	34.58	22.97	0.504	1.435
150	22.39	35.07	24.18	0.722	1.217
200	18.07	34.78	25.10	0.891	1.048
250	13.88	34.33	25.71	1.023	0.916
300	10.67	34.18	26.21	1.129	0.810
400	08.72	34.23	26.58	1.300	0.639
500	07.08	34.21	26.80	1.443	0.496
600	06.34	34.32	26.99	1.567	0.372
700	05.68	34.43	27.16	1.675	0.264
800	05.06	34.48	27.27	1.769	0.170
1000	04.29	34.50	27.37	1.939	0.000

STATION 14

M/V Hugh M. Smith: Cruise 10, 20°43'N., 157°29'W., July 26, 1951. Messenger time: 0137 GCT. Weather: 01, cloud coverage 3. Wind: 080°, 14 kt. Sea: 1-3 ft. Wire angle: 12°. Depth of water: 1500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	34.60	22.69	4.82	
10	26.02	34.61	22.76	4.84	
29	25.98	34.61	22.76	4.87	
59	25.38	34.54	22.90	4.92	
115	22.70	35.01	24.05	5.01	
224	15.90	34.54	25.43	4.18	
333	09.66	34.20	26.41	2.82	
438	07.74	34.16	26.67	1.83	
547	06.30	34.25	26.95	1.25	
653	05.49	34.35	27.12	0.87	
872	04.74	34.49	27.32	1.21	
1086	03.88	34.50	27.42	1.24	
1300	03.29	34.49	27.47	2.09	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.20	34.60	22.69	0.000	1.879
10	26.02	34.61	22.75	0.051	1.828
20	26.00	34.61	22.76	0.103	1.776
30	25.98	34.61	22.76	0.154	1.725
50	25.69	34.57	22.82	0.255	1.624
75	24.56	34.66	23.23	0.377	1.502
100	23.66	34.83	23.63	0.489	1.390
150	20.98	35.10	24.59	0.682	1.197
200	17.90	34.77	25.13	0.840	1.039
250	14.12	34.36	25.68	0.972	0.907
300	11.00	34.19	26.16	1.080	0.799
400	08.37	34.18	26.59	1.252	0.627
500	06.83	34.20	26.83	1.393	0.486
600	05.80	34.31	27.05	1.513	0.366
700	05.29	34.39	27.17	1.616	0.263
800	04.97	34.46	27.27	1.710	0.169
1000	04.20	34.50	27.38	1.879	0.000

STATION 15

M/V Hugh M. Smith: Cruise 10, 21°02'N., 157°29'W., July 26, 1951. Messenger time: 0524 GCT. Weather: 01, cloud coverage 4. Wind: 020°, 22 kt. Sea: 1-3 ft. Wire angle: 00°. Depth of water: 30 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.00	34.57	22.72	4.91	
10	26.08	34.61	22.74	4.92	
25	26.00	34.62	22.77	4.92	
35	25.83	34.58	22.79	4.88	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.05	34.57			
10	26.08	34.61			
20	26.05	34.62			
30	25.94	34.61			

STATION 16

M/V Hugh M. Smith: Cruise 10, 21°17'N., 157°26'W., July 26, 1951. Messenger time: 0840 GCT. Weather: 01, cloud coverage not recorded. Wind: 040°, 28 kt. Sea: 5-8 ft. Wire angle: 12°. Depth of water: 336 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.60	34.56	22.86	4.95	
10	25.58	34.61	22.89	4.93	
24	25.58	34.57	22.86	4.92	
48	25.58	34.61	22.89	4.93	
96	23.36	34.99	23.84	5.12	
192	17.56	34.82	25.26	4.59	
287	12.41	34.24	25.94	3.99	
383	09.33 1/	34.11	26.39	3.74	
383	09.39 T/	34.11	26.38		
479	06.75	34.11	26.77	2.18	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.57	34.56			
10	25.58	34.61			
20	25.58	34.58			
30	25.58	34.57			
50	25.58	34.62			
75	24.35	34.85			
100	23.27	35.00			
150	21.17	35.19			
200	17.10	34.76			
250	13.96	34.36			
300	11.95	34.21			
400	08.93	34.11			

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-salinity curve.

STATION 17

M/V Hugh M. Smith: Cruise 10, 21°45'N., 157°29'W., July 26, 1951. Messenger time: 1340 GCT. Weather: 22, cloud coverage not recorded. Wind: 040°, 18 kt. Sea: 3-5 ft. Wire angle: 15°. Depth of water: 1600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.80	34.65	22.87	4.85	
10	25.76	34.65	22.87	4.86	
25	25.68	34.78	22.99	4.88	
53	25.48	34.84	23.09	4.88	
104	22.47	35.19	24.25	5.16	
200	18.68	34.97	25.10	4.64	
292	12.35	34.17	25.90	4.42	
389	08.93 1/	34.13	26.47	3.06	
389	08.99 1/	34.13	26.46		
483	06.74	34.10	26.77	2.17	
576	05.70	34.18	26.96	1.24	
760	04.82	34.42	27.26	1.43	
953	04.00	34.47	27.39	1.14	
1142	03.38	34.49	27.46	1.44	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.76	34.65	22.86	0.000	1.857
10	25.76	34.65	22.86	0.050	1.807
20	25.70	34.73	22.94	0.100	1.757
30	25.62	34.79	23.01	0.149	1.708
50	25.47	34.84	23.09	0.246	1.611
75	23.64	35.07	23.82	0.357	1.500
100	22.52	35.18	24.22	0.455	1.402
150	20.96	35.25	24.71	0.631	1.226
200	18.68	34.97	25.09	0.787	1.070
250	15.28	34.48	25.52	0.924	0.933
300	11.94	34.16	25.96	1.040	0.817
400	08.68	34.14	26.51	1.226	0.631
500	06.48	34.12	26.81	1.372	0.485
600	05.60	34.20	26.99	1.494	0.363
700	05.08	34.37	27.18	1.600	0.257
800	04.66	34.43	27.28	1.693	0.164
1000	03.87	34.48	27.40	1.857	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-salinity curve.

STATION 18

M/V Hugh M. Smith: Cruise 10, 22°08'N., 157°32'W., July 26, 1951. Messenger time: 1832 GCT. Weather: 01, cloud coverage 5. Wind: 070°, 22 kt. Sea: 3-5 ft. Wire angle: 35°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
01	25.40	34.79	23.08	4.91	
10	25.41	34.78	23.07	4.90	
26	25.41	34.79	23.08	4.91	
51	25.39	34.80	23.09	4.90	
99	22.69	34.98	24.03	5.14	
190	20.41	35.21	24.83	4.86	
277	16.50	34.62	25.36	4.61	
359	10.66	34.14	26.19	4.67	
447	08.27 1/	34.09	26.54	2.72	
447	08.15 1/	34.09	26.56		
532	06.36	34.04	26.77	1.94	
707	04.88	34.29	27.15	1.46	
880	04.18	34.33	27.26	0.89	
1058	03.58	2/			

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.40	34.79	23.08	0.000	1.981
10	25.41	34.78	23.07	0.048	1.933
20	25.41	34.79	23.07	0.096	1.885
30	25.41	34.79	23.07	0.144	1.837
50	25.39	34.80	23.09	0.240	1.741
75	23.52	34.91	23.73	0.353	1.628
100	22.69	34.98	24.02	0.455	1.526
150	21.99	35.10	24.31	0.645	1.336
200	20.05	35.17	24.89	0.815	1.166
250	17.87	34.85	25.20	0.965	1.016
300	14.80	34.41	25.57	1.098	0.883
400	09.36	34.13	26.39	1.309	0.672
500	06.95	34.04	26.69	1.466	0.515
600	05.58	34.15	26.95	1.597	0.384
700	04.90	34.28	27.13	1.707	0.274
800	04.43	34.32	27.22	1.804	0.177
1000	03.78	34.37	27.32	1.981	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-salinity curve.

2/ Value did not fit the temperature-salinity curve.

STATION 19

M/V Hugh M. Smith: Cruise 10, 21°51'N., 156°45'W., July 27, 1951. Messenger time: 0308 GCT. Weather: 01, cloud coverage 8. Wind: 090°, 18 kt. Sea: 3-5 ft. Wire angle: 25°. Depth of water: 2750 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
01	25.60	34.66	23.00	4.90	
09	25.59	34.63	22.74	4.85	
27	25.54	34.60	22.70	4.87	
53	24.86	34.62	22.76	5.08	
106	22.68	35.09	23.32	5.14	
206	17.72	34.89	24.63	4.80	
304	11.76	34.10	25.96	3.60	
396	08.82	34.05	27.08	3.55	
496	06.68	34.04	27.56	2.23	
590	05.63	34.14	27.32	1.25	
786	04.35	34.34	27.45	1.34	
983	03.77	34.42	27.54	1.39	
1182	03.34	1/			

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.57	34.66	22.93	0.000	1.891
10	25.59	34.63	22.90	0.050	1.841
20	25.57	34.61	22.89	0.099	1.792
30	25.54	34.60	22.89	0.149	1.742
50	25.54	34.62	22.91	0.249	1.642
75	24.10	34.78	23.46	0.367	1.524
100	23.00	35.07	24.00	0.472	1.419
150	19.60	35.12	24.97	0.647	1.244
200	17.96	34.87	25.20	0.794	1.097
250	15.40	34.46	25.48	0.929	0.962
300	11.90	34.11	25.93	1.047	0.844
400	08.72	34.05	26.43	1.238	0.653
500	06.60	34.04	26.73	1.391	0.500
600	05.55	34.15	26.95	1.519	0.372
700	04.80	34.28	27.14	1.628	0.263
800	04.29	34.35	27.26	1.723	0.168
1000	03.72	34.43	27.38	1.891	0.000

1/ Value did not fit the temperature-salinity curve.

STATION 20

M/V Hugh M. Smith: Cruise 10, 21°10'N., 156°35'W., July 27, 1951. Messenger time: 0938 GCT. Weather: 01, cloud coverage not recorded. Wind: 060°, 3 kt. Sea: 1-3 ft. Wire angle: not recorded. Depth of water 256 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.20	34.78	23.14	4.87	
10	25.20	34.76	23.12	4.88	
24	25.20	34.77	23.13	4.88	
49	25.06	34.78	23.18	4.88	
99	23.28	35.03	23.90	5.12	
197	19.54	35.09	24.97	4.63	
295	11.10	34.11	26.08	4.30	
344	09.77	34.14	26.34	3.38	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.19	34.78			
10	25.20	34.76			
20	25.20	34.76			
30	25.19	34.77			
50	25.05	34.78			
75	24.22	34.86			
100	23.27	35.03			
150	21.38	35.20			
200	19.40	35.07			
250	14.55	34.37			
300	11.02	34.11			

STATION 21

M/V Hugh M. Smith: Cruise 10, 20°50'N., 156°45'W., July 27, 1951. Messenger time: 1340 GCT. Weather: 01, cloud coverage not recorded. Wind: 060°, 6 kt. Sea: < 1 ft. Wire angle: 00°. Depth of water: 27 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.80	34.59	22.82	4.80	
10	25.65	34.57	22.84	4.82	
25	25.66	34.57	22.84	4.80	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.77	34.59			
10	25.65	34.57			
20	25.65	34.57			

STATION 22

M/V Hugh M. Smith: Cruise 10, 20°20'N., 156°39'W., July 27, 1951. Messenger time: 1837 GCT. Weather: 01, cloud coverage 2. Wind: 060°, 24 kt. Sea: 3-5 ft. Wire angle: 38°. Depth of water: 1200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
01	25.80	34.64	22.84	4.93	
08	25.86	34.63	22.82	4.86	
22	25.87	1/		4.88	
45	25.86	34.61	22.81	4.84	
86	25.00	34.68	23.12	4.92	
162	19.99	34.98	24.77	4.72	
240	16.16	34.65	25.46	4.31	
318	11.15	34.20	26.14	3.54	
400	08.58	34.20	26.58	2.28	
481	06.86	34.22	26.85	1.33	
654	05.56	34.45	27.20	1.65	
833	04.77	34.45	27.29	1.02	
1021	03.74	2/			

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.83	34.64	22.83	0.000	1.882
10	25.86	34.63	22.81	0.050	1.832
20	25.87	34.62	22.80	0.101	1.781
30	25.87	34.61	22.80	0.152	1.730
50	25.86	34.61	22.80	0.253	1.629
75	25.70	34.61	22.85	0.380	1.502
100	23.60	34.88	23.68	0.496	1.386
150	20.43	34.99	24.65	0.686	1.196
200	17.50	34.79	25.25	0.839	1.043
250	14.50	34.45	25.67	0.969	0.913
300	11.95	34.22	26.01	1.081	0.801
400	08.58	34.20	26.57	1.262	0.620
500	06.67	34.23	26.87	1.401	0.481
600	05.89	34.34	27.06	1.518	0.364
700	05.37	34.41	27.18	1.621	0.261
800	04.92	34.44	27.26	1.715	0.167
1000	03.85	34.48	27.41	1.882	0.000

1/ Sample lost.

2/ Value did not fit the temperature-salinity curve.

STATION 23

M/V Hugh M. Smith: Cruise 10, 19°37'N., 156°40'W., July 27, 1951. Messenger time: 0017 GCT. Weather: 01, cloud coverage 1. Wind: 180°, 10 kt. Sea: <1 ft. Wire angle: 35°. Depth of water: 2550 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.40	34.62	22.65	4.84	
09	25.82	34.66	22.86	4.86	
25	25.52	34.66	22.95	4.87	
50	23.82	34.69	23.48	4.98	
96	22.27	35.08	24.22	5.04	
180	16.92	34.83	25.42	4.93	
255	12.48	34.33	26.00	3.77	
329	09.58 1/	34.18	26.40	2.96	
329	09.64 1/	34.18	26.39		
406	07.85	34.17	26.66	2.07	
490	06.98	34.24	26.85	1.17	
632	05.85	34.40	27.12	1.13	
789	05.18	34.44	27.23	1.00	
964	04.32	34.44	27.33	1.17	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.38	34.62	22.64	0.000	1.753
10	25.81	34.66	22.85	0.051	1.702
20	25.60	34.66	22.92	0.101	1.652
30	25.27	34.66	23.02	0.150	1.603
50	23.82	34.69	23.48	0.243	1.510
75	23.04	34.93	23.88	0.349	1.404
100	22.17	35.08	24.25	0.446	1.307
150	18.96	35.02	25.06	0.613	1.140
200	15.28	34.64	25.65	0.747	1.006
250	12.70	34.35	25.96	0.860	0.893
300	10.65	34.21	26.24	0.959	0.794
400	07.92	34.17	26.65	1.125	0.628
500	06.90	34.26	26.87	1.261	0.492
600	06.08	34.38	27.07	1.378	0.375
700	05.53	34.42	27.17	1.481	0.272
800	05.11	34.44	27.24	1.577	0.176
1000	04.13	34.44	27.34	1.753	0.000

1/ Thermometers did not agree within 0.02 °C tolerance. Average value used in constructing temperature-salinity curve.

STATION 24

M/V Hugh M. Smith: Cruise 10, 19°02'N., 156°40'W., July 28, 1951. Messenger time: 0542 GCT. Weather: 01, cloud coverage 6. Wind: 120°, 18 kt. Sea: 3-5 ft. Wire angle: 15°. Depth of water: 2530 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
01	26.40	34.63	22.64	4.85	
11	26.44	34.64	22.64	4.88	
31	26.40	34.62	22.64	4.88	
60	25.94	34.60	22.77	4.90	
118	24.08	34.72	23.43	4.92	
232	16.24	34.60	25.40	4.20	
345	09.34	34.17	26.43	3.09	
454	07.56	34.23	26.75	1.39	
569	06.72	34.34	26.96	0.80	
680	05.66	34.41	27.15	0.86	
907	04.72	34.49	27.32	1.36	
1127	03.98	34.51	27.42	1.18	
1340	03.40	34.54	27.50	1.47	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.43	34.63	22.64	0.000	1.936
10	26.44	34.64	22.64	0.052	1.884
20	26.42	34.63	22.64	0.104	1.832
30	26.40	34.62	22.64	0.157	1.779
50	26.22	34.60	22.68	0.261	1.675
75	25.66	34.61	22.86	0.389	1.547
100	24.98	34.64	23.09	0.512	1.424
150	21.48	35.01	24.38	0.722	1.214
200	18.40	34.86	25.08	0.886	1.050
250	14.80	34.45	25.61	1.022	0.914
300	11.40	34.22	26.11	1.132	0.804
400	08.15	34.20	26.64	1.305	0.631
500	07.05	34.29	26.87	1.442	0.494
600	06.49	34.36	27.00	1.562	0.374
700	05.54	34.42	27.17	1.669	0.267
800	05.05	34.46	27.26	1.764	0.172
1000	04.40	34.50	27.36	1.936	0.000

STATION 25

M/V Hugh M. Smith: Cruise 10, 18°22'N., 156°40'W., July 28, 1951. Messenger time: 1205 GCT. Weather: 02, cloud coverage not recorded. Wind: 040°, 21 kt. Sea: 5-8 ft. Wire angle: 25°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.80	34.67	22.86	4.88	
07	25.84	34.65	22.84	4.85	
21	25.86	34.67	22.85	4.86	
42	25.84	34.69	22.87	4.84	
80	25.50	34.68	22.97	4.90	
150	22.04	34.91	24.16	5.05	
218	18.12	34.82	25.12	4.51	
278	12.84	34.28	25.89	3.84	
338	09.51	34.18	26.41	3.05	
395	07.94	34.19	26.67	2.00	
511	06.38	34.42	27.06	1.54	
645	05.60	34.39	27.14	0.87	
811	04.86	34.44	27.27	1.00	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.84	34.67	22.85	0.000	1.913
10	25.85	34.65	22.83	0.050	1.863
20	25.86	34.67	22.84	0.101	1.812
30	25.85	34.68	22.86	0.151	1.762
50	25.84	34.69	22.87	0.251	1.662
75	25.50	34.68	22.96	0.376	1.537
100	25.32	34.68	23.02	0.498	1.415
150	22.04	34.91	24.15	0.716	1.197
200	19.38	34.91	24.87	0.891	1.022
250	15.45	34.50	25.50	1.034	0.879
300	11.55	34.22	26.08	1.148	0.765
400	07.84	34.19	26.68	1.319	0.594
500	06.48	34.41	27.04	1.446	0.467
600	05.78	34.41	27.13	1.552	0.361
700	05.33	34.40	27.18	1.651	0.262
800	04.90	34.44	27.26	1.745	0.168
1000	04.10	34.50	27.40	1.913	0.000

STATION 26

M/V Hugh M. Smith: Cruise 10, 18°10'N., 155°35'W., July 29, 1951. Messenger time: 0845 GCT. Weather: 01, cloud coverage not recorded. Wind: 080°, 20 kt. Sea: 3-5 ft. Wire angle: 17°. Depth of water: 2675 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.20	34.60	23.00	4.88	
10	25.22	34.69	23.06	4.88	
29	25.22	34.61	23.00	4.88	
56	25.01	34.63	23.08	4.93	
112	22.14	35.04	24.23	5.10	
218	14.04	34.35	25.69	3.61	
323	09.03	34.19	26.50	2.82	
424	07.31	34.22	26.78	1.33	
529	06.52	34.36	27.00	1.08	
631	05.78	34.40	27.13	0.71	
840	04.74	34.49	27.32	1.08	
1043	04.02	34.52	27.42	1.15	
1246	03.54	34.54	27.49	1.25	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.20	34.60	22.99	0.000	1.744
10	25.22	34.69	23.06	0.048	1.696
20	25.22	34.66	23.03	0.097	1.647
30	25.22	34.61	23.00	0.145	1.599
50	25.12	34.62	23.03	0.243	1.501
75	23.52	34.87	23.70	0.356	1.388
100	22.60	35.00	24.06	0.458	1.286
150	20.40	35.06	24.72	0.637	1.107
200	16.67	34.68	25.36	0.787	0.957
250	11.30	34.21	26.12	0.902	0.842
300	09.57	34.19	26.41	0.993	0.751
400	07.62	34.21	26.73	1.147	0.597
500	06.73	34.33	26.94	1.276	0.468
600	06.00	34.39	27.09	1.388	0.356
700	05.38	34.44	27.20	1.489	0.255
800	04.89	34.49	27.30	1.580	0.164
1000	04.15	34.52	27.41	1.744	0.000

STATION 27

M/V Hugh M. Smith: Cruise 10, 18°37'N., 154°27'W., July 29, 1951. Messenger time: 1820 GCT. Weather: 01, cloud coverage 5. Wind: 070°, 14 kt. Sea: 1-3 ft. Wire angle: 35°. Depth of water: 2900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.20	34.61	23.00	4.86	
09	25.23	34.56	22.96	4.85	
26	25.24	34.56	22.96	4.85	
51	24.56	34.55	23.16	4.97	
97	22.50	35.00	24.10	5.09	
188	16.54	34.76	25.46	4.63	
276	10.34	34.16	26.26	3.12	
359	1/	2/		1.31	
444	07.42	34.34	26.86	0.74	
527	06.87	34.38	26.97	0.42	
701	05.46	34.44	27.20	0.92	
884	04.82	34.47	27.30	0.64	
1075	04.14	34.41	27.33	0.68	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.21	34.61	23.00	0.000	1.741
10	25.23	34.56	22.96	0.049	1.692
20	25.24	34.56	22.95	0.098	1.643
30	25.24	34.56	22.95	0.147	1.594
50	24.57	34.55	23.15	0.244	1.497
75	23.22	34.88	23.79	0.355	1.386
100	22.42	35.01	24.12	0.455	1.286
150	19.65	35.04	24.90	0.629	1.112
200	15.35	34.61	25.61	0.767	0.974
250	11.20	34.18	26.12	0.877	0.864
300	09.80	34.18	26.36	0.970	0.771
400	07.93	34.30	26.74	1.125	0.616
500	07.05	34.36	26.92	1.254	0.487
600	06.26	34.41	27.07	1.369	0.372
700	05.47	34.44	27.19	1.471	0.270
800	05.10	34.46	27.25	1.565	0.176
1000	04.40	34.46	27.33	1.741	0.000

1/ Values did not fit the temperature-depth curve.

2/ Value did not fit the temperature-salinity curve.

STATION 28

M/V Hugh M. Smith: Cruise 10, 19°13'N., 154°30'W., July 29, 1951. Messenger time: 2330 GCT. Weather: 01, cloud coverage 5. Wind: 050°, 18 kt. Sea: 3-5 ft. Wire angle: 27°. Depth of water: 3000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.30	34.60	22.97	4.89	
09	25.26	34.60	22.98	4.92	
27	25.16	34.60	23.01	4.93	
53	25.13	34.59	23.01	4.90	
104	22.68	35.10	24.12	5.19	
204	17.54	34.78	25.23	4.50	
303	10.28	34.16	26.27	3.56	
398	08.95 1/	2/		0.80	
398	09.01 1/				
497	07.65	34.35	26.84	0.54	
593	06.62	34.38	27.00	0.44	
795	05.32	34.47	27.24	0.91	
997	04.30	34.46	27.35	0.90	
1202	03.76	34.49	27.43	2.38	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.28	34.60	22.97	0.000	1.849
10	25.25	34.60	22.98	0.049	1.800
20	25.20	34.60	22.99	0.098	1.751
30	25.16	34.60	23.01	0.147	1.702
50	25.13	34.59	23.01	0.244	1.605
75	24.05	34.73	23.44	0.361	1.488
100	22.82	35.07	24.05	0.466	1.383
150	20.52	35.10	24.71	0.646	1.203
200	17.72	34.82	25.22	0.798	1.051
250	13.50	34.30	25.76	0.926	0.923
300	10.38	34.16	26.25	1.030	0.819
400	08.95	34.22	26.53	1.201	0.648
500	07.62	34.36	26.84	1.345	0.504
600	06.55	34.39	27.01	1.467	0.382
700	05.87	34.42	27.13	1.575	0.274
800	05.30	34.48	27.24	1.673	0.176
1000	04.25	34.46	27.35	1.849	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

2/ Value did not fit the temperature-salinity curve.

STATION 29

M/V Hugh M. Smith: Cruise 10, 19°55'N., 154°29'W., July 30, 1951. Messenger time: 0530 GCT. Weather: 01, cloud coverage 9. Wind: 020°, 13 kt. Sea: 1-3 ft. Wire angle: 25°. Depth of water: no data.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.30	34.63	22.98	4.85	
10	25.34	34.65	22.99	4.89	
27	25.30	34.65	23.01	4.88	
54	24.44	34.54	23.18	5.08	
106	22.45	34.98	24.10	5.04	
210	17.92	34.77	25.14	4.46	
311	10.41	34.22	26.29	2.81	
408	09.19 1/	2/		1.05	
408	09.04 1/				
510	07.21	34.30	26.86	0.83	
609	06.48	34.39	27.03	0.62	
816	05.08	34.46	27.26	1.08	
1023	04.33	34.49	27.37	0.91	
1231	03.70	2/			

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.33	34.63	22.98	0.000	1.871
10	25.34	34.65	22.99	0.049	1.822
20	25.31	34.65	23.00	0.098	1.773
30	25.29	34.65	23.01	0.146	1.725
50	25.12	34.54	22.97	0.244	1.627
75	23.19	34.79	23.74	0.358	1.513
100	22.55	34.96	24.05	0.460	1.411
150	21.25	35.08	24.50	0.644	1.227
200	18.75	34.86	24.99	0.808	1.063
250	13.70	34.34	25.75	0.941	0.930
300	10.67	34.22	26.24	1.045	0.826
400	09.22	34.24	26.50	1.218	0.653
500	07.33	34.29	26.83	1.364	0.507
600	06.51	34.38	27.01	1.486	0.385
700	05.79	34.43	27.15	1.593	0.278
800	05.16	34.46	27.25	1.690	0.181
1000	04.86	34.49	27.30	1.871	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

2/ Value did not fit the temperature-salinity curve.

STATION 30

M/V Hugh M. Smith: Cruise 10, 20°30'N., 154°30'W., July 30, 1951. Messenger time: 1115 GCT. Weather: 02, cloud coverage not recorded. Wind: 080°, 22 kt. Sea: 3-5 ft. Wire angle: 25°. Depth of water: 3000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.30	34.63	22.99	4.89	
09	25.33	34.61	22.97	4.88	
27	25.32	34.62	22.98	4.89	
53	25.25	34.59	22.98	4.91	
106	22.57	34.94	24.03	5.16	
208	18.38	34.88	25.10	4.55	
309	11.06	34.19	26.15	3.09	
407	09.00 1/	2/		1.22	
407	09.06 1/				
510	06.90	34.23	26.85	1.16	
608	06.13	34.33	27.03	0.72	
816	05.04	34.50	27.30	1.21	
1023	04.33	34.51	27.38	1.03	
1229	03.69	2/		3/	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.32	34.63	22.98	0.000	1.893
10	25.33	34.61	22.96	0.049	1.844
20	25.32	34.62	22.97	0.098	1.795
30	25.31	34.62	22.98	0.147	1.746
50	25.28	34.59	22.96	0.245	1.648
75	23.75	34.66	23.47	0.362	1.531
100	22.73	34.91	23.96	0.468	1.425
150	21.50	35.12	24.46	0.656	1.237
200	19.00	34.94	24.99	0.820	1.073
250	15.10	34.49	25.57	0.958	0.935
300	11.48	34.20	26.08	1.071	0.822
400	09.14	34.19	26.48	1.253	0.640
500	07.05	34.22	26.81	1.400	0.493
600	06.19	34.32	27.01	1.523	0.370
700	05.60	34.44	27.18	1.629	0.264
800	05.10	34.49	27.28	1.723	0.170
1000	04.39	34.51	27.37	1.893	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

2/ Value did not fit the temperature-salinity curve.

3/ Value did not fit the temperature-oxygen curve.

STATION 31

M/V Hugh M. Smith: Cruise 10, 21°06'N., 154°54'W., July 30, 1951. Messenger time: 1700 GCT. Weather: 01, cloud coverage 5. Wind: 070°, 18 kt. Sea: 1-3 ft. Wire angle: 10°. Depth of water: no data.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.60	34.95	23.13	4.78	
10	25.64	34.96	23.14	4.82	
31	25.68	34.96	23.12	4.82	
61	23.60	34.97	23.76	5.21	
120	20.94	35.27	24.73	4.94	
235	14.92	34.50	25.62	4.62	
349	09.52	34.14	26.38	3.12	
457	06.92	34.05	26.71	2.06	
569	05.44	34.14	26.98	1.10	
679	04.84	34.23	27.11	0.64	
900	04.20	34.50	27.39	1.46	
1117	03.62	34.50	27.45	1.40	
1330	03.16	34.55	27.53	1.60	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.64	34.95	23.12	0.000	1.805
10	25.64	34.96	23.13	0.047	1.758
20	25.66	34.96	23.13	0.095	1.710
30	25.68	34.96	23.12	0.143	1.662
50	25.63	34.96	23.13	0.238	1.567
75	23.25	35.05	23.91	0.348	1.457
100	21.93	35.24	24.43	0.442	1.363
150	19.97	35.18	24.92	0.608	1.197
200	17.38	34.83	25.31	0.754	1.051
250	13.92	34.39	25.75	0.880	0.925
300	11.38	34.21	26.11	0.987	0.818
400	08.20	34.08	26.54	1.165	0.640
500	06.23	34.07	26.81	1.309	0.496
600	05.22	34.16	27.00	1.431	0.374
700	04.78	34.25	27.12	1.539	0.266
800	04.48	34.34	27.23	1.636	0.169
1000	03.95	34.50	27.41	1.805	0.000

STATION 32

M/V Hugh M. Smith: Cruise 10, 21°25'N., 155°30'W., July 30, 1951. Messenger time: 2107 GCT. Weather: 02, cloud coverage 8. Wind: 100°, 21 kt. Sea: 3-5 ft. Wire angle: 16°. Depth of water: no data.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.50	34.68	22.96	4.90	
10	25.53	34.65	22.94	4.92	
30	25.46	34.64	22.95	4.90	
59	24.92	34.64	23.12	5.07	
116	21.66	34.96	24.30	5.01	
233	12.44	34.24	25.94	4.26	
346	09.04	34.23	26.53	2.39	
455	06.36	34.08	26.80	1.89	
568	05.42	34.22	27.03	0.70	
678	05.00	34.38	27.21	0.85	
903	04.38	34.49	27.36	1.04	
1122	03.74	34.52	27.45	1.33	
1337	03.27	34.52	27.50	1.44	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.53	34.68	22.95	0.000	1.757
10	25.53	34.65	22.93	0.049	1.708
20	25.50	34.64	22.93	0.099	1.658
30	25.46	34.64	22.95	0.148	1.609
50	25.43	34.64	22.95	0.247	1.510
75	24.23	34.69	23.35	0.365	1.392
100	22.75	34.84	23.90	0.473	1.284
150	19.43	34.94	24.88	0.652	1.105
200	14.50	34.40	25.63	0.791	0.966
250	11.83	34.23	26.04	0.902	0.855
300	10.40	34.24	26.31	0.998	0.759
400	07.47	34.12	26.68	1.159	0.598
500	05.88	34.12	26.89	1.292	0.465
600	05.26	34.29	27.10	1.405	0.352
700	04.95	34.40	27.22	1.504	0.253
800	04.67	34.45	27.29	1.594	0.163
1000	04.09	34.52	27.41	1.757	0.000

STATION 33

M/V Hugh M. Smith: Cruise 10, 21°51'N., 156°45'W., July 31, 1951. Messenger time: 0901 GCT. Weather: 01, cloud coverage not recorded. Wind: 060°, 21 kt. Sea: 1-3 ft. Wire angle: 20°. Depth of water: 2700 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
01	25.50	34.73	23.01	4.88	
10	25.49	34.71	22.99	4.90	
28	25.49	34.70	22.98	4.89	
56	25.40	34.69	23.01	4.94	
112	22.36	35.15	24.25	5.17	
221	15.90	1/		4.18	
330	11.16	34.23	26.17	4.91	
434	08.28	34.13	26.57	2.66	
543	06.15	34.09	26.84	1.66	
647	05.18	34.20	27.04	0.95	
864	04.26	34.44	27.34	1.44	
1077	03.64	34.49	27.44	1.27	
1287	03.16	34.51	27.50	1.65	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.48	34.73	23.01	0.000	1.859
10	25.49	34.71	22.99	0.049	1.810
20	25.49	34.70	22.98	0.098	1.761
30	25.48	34.70	22.98	0.147	1.712
50	25.43	34.69	22.99	0.245	1.614
75	23.75	34.84	23.61	0.360	1.499
100	22.65	35.08	24.11	0.462	1.397
150	20.15	35.18	24.87	0.636	1.223
200	17.07	34.77	25.33	0.782	1.077
250	14.52	34.46	25.67	0.910	0.949
300	12.42	34.28	25.96	1.023	0.836
400	09.12	34.17	26.46	1.211	0.648
500	06.90	34.09	26.73	1.363	0.496
600	05.55	34.14	26.95	1.491	0.368
700	04.86	34.29	27.15	1.601	0.258
800	04.45	34.40	27.28	1.695	0.164
1000	03.89	34.48	27.40	1.859	0.000

1/ No sample.

STATION 1

M/V Hugh M. Smith: Cruise 12, 20°18'N., 159°18'W., October 24, 1951. Messenger time: 1320 GCT. Weather: 00, cloud coverage 3. Wind: 120°, 9 kt. Sea: 3-5 ft. Wire angle: 18°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	34.96	22.98		0.32
10	26.17	34.97	22.98		0.41
29	26.20	34.96	22.96		0.18
59	24.84	34.90	23.33		0.31
115	21.34	35.01	24.43		0.42
230	13.49	34.34	25.80		1.28
341	09.20	34.16	26.45		1.99
446	07.18	34.22	26.80		2.73
555	06.06	34.29	27.01		3.07
662	05.38	34.38	27.16		3.20
881	04.54	34.43	27.30		3.22
1093	03.82	34.43	27.37		2.91
1305	03.29	34.38	27.38		2.60

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.15	34.96	22.97	0.000	1.777
10	26.17	34.97	22.97	0.049	1.728
20	26.19	34.97	22.97	0.098	1.679
30	26.20	34.96	22.96	0.147	1.630
50	26.18	34.92	22.93	0.246	1.531
75	23.38	34.98	23.82	0.359	1.418
100	21.95	35.00	24.25	0.457	1.320
150	19.88	34.95	24.77	0.631	1.146
200	16.25	34.62	25.41	0.777	1.000
250	12.60	34.28	25.93	0.897	0.880
300	10.60	34.18	26.22	0.997	0.780
400	07.92	34.18	26.66	1.163	0.614
500	06.52	34.26	26.92	1.296	0.481
600	05.71	34.32	27.07	1.410	0.367
700	05.18	34.40	27.20	1.512	0.265
800	04.78	34.43	27.27	1.605	0.172
1000	04.15	34.44	27.34	1.777	0.000

STATION 2

M/V Hugh M. Smith: Cruise 12, 21°01'N, 159°14'W., October 24, 1951. Messenger time: 2115 GCT. Weather: 00, cloud coverage 7. Wind: 120°, 9 kt. Sea: 1-3 ft. Wire angle: 24°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.50	34.88	22.81		0.32
10	26.44	34.89	22.83		0.37
28	26.43	34.88	22.83		0.32
55	26.42	34.88	22.83		0.27
109	22.22	34.98	24.16		0.35
214	16.68	34.67	25.35		0.82
317	10.25	34.14	26.26		1.76
414	07.78	34.13	26.64		2.43
518	06.62	34.31	26.95		2.96
617	05.71	34.30	27.06		3.10
617					3.21 1/
825	04.82	34.42	27.27		3.17
1032	04.04	34.50	27.41		3.05
1032					3.16 1/
1239	03.48				

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.48	34.88	22.81	0.000	1.851
10	26.44	34.89	22.83	0.050	1.801
20	26.43	34.89	22.83	0.101	1.750
30	26.43	34.88	22.82	0.151	1.700
50	26.43	34.88	22.82	0.252	1.599
75	25.25	34.90	23.21	0.374	1.477
100	22.72	34.98	24.01	0.482	1.369
150	20.61	34.97	24.59	0.666	1.185
200	17.62	34.75	25.19	0.822	1.029
250	13.10	34.32	25.86	0.949	0.902
300	10.87	34.17	26.17	1.052	0.799
400	08.01	34.11	26.59	1.224	0.627
500	06.77	34.31	26.92	1.360	0.491
600	05.83	34.30	27.04	1.476	0.375
700	05.31	34.35	27.14	1.581	0.270
800	04.92	34.41	27.23	1.678	0.173
1000	04.15	34.49	27.38	1.851	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 3

M/V Hugh M. Smith: Cruise 12, 21°46'N., 159°12'W., October 25, 1951. Messenger time: 0443 GCT. Weather: 02, cloud coverage 7. Wind: 320°, 8 kt. Sea: 3-5 ft. Wire angle: 05°. Depth of water: 1850 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.80	34.88	22.70		0.27
10	26.64	34.87	22.75		0.28
31	26.60	34.87	22.77		0.29
31					0.23 1/
60	26.58	34.87	22.77		0.30
118	21.85	35.12	24.37		0.33
234	15.42	34.52	25.53		0.96
234					0.91 1/
346	09.21	34.13	26.42		1.96
455	07.06	34.10	26.72		2.54
568	05.92	34.21	26.96		2.98
677	04.94	34.29	27.14		3.22
900	04.50	34.46	27.32		3.18
1114	03.84	34.50	27.43		3.20
1324	03.31	34.50	27.48		3.02

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.83	34.88	22.70	0.000	1.871
10	26.64	34.87	22.75	0.051	1.820
20	26.62	34.87	22.76	0.102	1.769
30	26.60	34.87	22.76	0.154	1.717
50	26.59	34.87	22.77	0.256	1.615
75	25.85	34.89	23.01	0.381	1.490
100	23.25	35.07	23.93	0.492	1.379
150	20.28	35.02	24.72	0.675	1.196
200	18.10	34.82	25.12	0.830	1.041
250	14.20	34.42	25.71	0.961	0.910
300	10.95	34.20	26.18	1.068	0.803
400	07.97	34.10	26.59	1.239	0.632
500	06.58	34.14	26.81	1.381	0.490
600	05.59	34.22	27.00	1.503	0.368
700	04.87	34.32	27.17	1.608	0.263
800	04.68	34.42	27.27	1.702	0.169
1000	04.19	34.49	27.38	1.871	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 4

M/V Hugh M. Smith: Cruise 12, 22°28'N., 159°14'W., October 25, 1951. Messenger time: 1133 GCT. Weather: 00, cloud coverage 3. Wind: 060°, 6 kt. Sea: 1-3 ft. Wire angle: 12°. Depth of water: 1830 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	34.93	22.92		0.33
00					0.26 1/
10	26.26	34.91	22.91		0.31
10					0.24 1/
29	26.29	34.92	22.90		0.38
29					0.28 1/
58	26.08	34.93	22.97		0.25
118	21.45	35.04	24.42		0.40
231	14.90	34.42	25.57		1.07
344	09.44	34.12	26.38		1.51
453	07.02	34.04	26.68		2.25
565	05.59	34.11	26.92		2.97
673	05.58	34.34	27.10		3.16
896	04.44	34.43	27.31		3.18
1110	03.82	34.51	27.44		3.07
1318	03.28	34.47	27.46		2.11

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.25	34.93	22.92	0.000	1.852
10	26.26	34.91	22.90	0.050	1.802
20	26.28	34.91	22.89	0.099	1.753
30	26.29	34.92	22.90	0.149	1.703
50	26.28	34.93	22.91	0.249	1.603
75	24.45	34.95	23.49	0.366	1.486
100	22.17	35.03	24.21	0.469	1.383
150	19.75	34.94	24.80	0.643	1.209
200	16.25	34.55	25.36	0.790	1.062
250	14.02	34.35	25.69	0.916	0.936
300	11.46	34.21	26.09	1.025	0.827
400	07.96	34.06	26.56	1.202	0.650
500	06.35	34.05	26.77	1.347	0.505
600	05.58	34.20	26.99	1.472	0.380
700	05.48	34.35	27.12	1.580	0.272
800	04.91	34.39	27.22	1.679	0.173
1000	04.12	34.49	27.39	1.852	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 5

M/V Hugh M. Smith: Cruise 12, 23°02'N., 159°15'W., October 25, 1951. Messenger time: 1740 GCT. Weather: 00, cloud coverage 3. Wind: 170°, 8 kt. Sea: 1-3 ft. Wire angle: 12°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	34.97	22.96		0.25
10	26.22	34.97	22.96		0.26
25	26.22	34.95	22.95		0.25
54	26.23	34.92	22.92		0.80
105	22.07	35.14	24.33		0.94
207	17.23	34.79	25.32		1.08
307	12.12	34.28	26.03		1.13
412	08.14 1/	34.04	26.52		1.88
412	08.21 T/	34.04	26.51		
514	07.02	34.22	26.82		2.96
615	05.98	34.28	27.01		3.17
812	05.04	34.41	27.23		3.30
1013	04.20	34.46	27.36		3.18
1207	03.63	34.47	27.42		2.11

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.22	34.97	22.96	0.000	1.862
10	26.22	34.97	22.96	0.049	1.813
20	26.22	34.96	22.95	0.098	1.764
30	26.22	34.94	22.94	0.148	1.714
50	26.23	34.92	22.92	0.247	1.615
75	23.90	35.08	23.75	0.361	1.501
100	22.25	35.14	24.27	0.460	1.402
150	19.72	35.04	24.88	0.630	1.232
200	17.62	34.84	25.26	0.778	1.084
250	14.42	34.48	25.71	0.907	0.955
300	12.35	34.30	25.99	1.018	0.844
400	08.42	34.05	26.48	1.204	0.658
500	07.17	34.21	26.79	1.352	0.510
600	06.12	34.26	26.97	1.477	0.385
700	05.47	34.38	27.15	1.586	0.276
800	05.09	34.41	27.21	1.684	0.178
1000	04.22	34.46	27.35	1.862	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

STATION 6

M/V Hugh M. Smith: Cruise 12, 22°46'N., 158°25'W., October 26, 1951. Messenger time: 0115 GCT. Weather: 00, cloud coverage 4. Wind: 160°, 11 kt. Sea: 1-3 ft. Wire angle: 18°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.30	34.79	22.79		0.19
10	26.21	34.85	22.87		0.19
10					0.29 1/
29	26.24	34.85	22.87		0.27
29					0.20 1/
57	25.92	34.85	22.97		0.23
114	22.94	35.06	24.02		0.25
224	16.20	34.55	25.37		0.74
333	10.18	34.16	26.28		1.55
437	07.55	33.99	26.57		1.95
545	05.76	34.04	26.84		2.72
649	04.92	34.17	27.05		3.06
865	04.20	34.39	27.30		3.09
1074	03.76	34.48	27.42		2.98
1282	03.22	34.49	27.48		1.53

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.34	34.79	22.79	0.000	1.915
10	26.31	34.85	22.84	0.051	1.864
20	26.27	34.85	22.85	0.101	1.814
30	26.23	34.85	22.86	0.151	1.764
50	25.95	34.85	22.95	0.250	1.665
75	25.88	34.85	22.97	0.374	1.541
100	23.98	34.99	23.66	0.489	1.426
150	20.80	35.04	24.59	0.681	1.234
200	18.07	34.74	25.07	0.840	1.075
250	14.65	34.45	25.64	0.975	0.940
300	11.55	34.25	26.11	1.085	0.830
400	08.38	34.04	26.48	1.265	0.650
500	06.38	33.99	26.72	1.416	0.499
600	05.25	34.10	26.95	1.545	0.370
700	04.64	34.25	27.14	1.654	0.261
800	04.31	34.36	27.26	1.748	0.167
1000	03.90	34.47	27.39	1.915	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 7

M/V Hugh M. Smith: Cruise 12, 22°09'N., 158°24'W., October 26, 1951. Messenger time: 0805 GCT. Weather: 00, cloud coverage 6. Wind: 060°, 19 kt. Sea: 5-8 ft. Wire angle: 10°. Depth of water: 2700 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.50	34.86	22.81		0.27
10	26.46	34.84	22.79		0.30
29	26.24	34.91	22.91		0.24
60	26.14	34.89	22.93		0.36
118	22.62	35.03	24.09		0.51
232	15.59	34.52	25.49		0.94
346	09.36	34.10	26.37		1.87
454	07.35	34.10	26.69		2.58
568	06.03	34.23	26.96		3.02
678	05.30	34.36	27.15		3.27
902	04.44	34.44	27.32		3.28
1117	03.84	34.50	27.43		3.15
1325	03.30	34.49	27.47		2.58

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.46	34.86	22.80	0.000	1.881
10	26.46	34.84	22.79	0.051	1.830
20	26.41	34.89	22.84	0.101	1.780
30	26.23	34.91	22.91	0.151	1.730
50	26.16	34.89	22.92	0.251	1.630
75	25.10	34.88	23.24	0.371	1.510
100	23.40	34.99	23.83	0.481	1.400
150	20.73	35.02	24.60	0.669	1.212
200	18.00	34.76	25.10	0.827	1.054
250	14.11	34.39	25.71	0.959	0.922
300	11.10	34.19	26.14	1.067	0.814
400	08.23	34.07	26.53	1.243	0.638
500	06.73	34.15	26.80	1.389	0.492
600	05.78	34.27	27.02	1.511	0.370
700	05.20	34.38	27.18	1.615	0.266
800	04.77	34.41	27.25	1.709	0.172
1000	04.15	34.48	27.37	1.881	0.000

STATION 8

M/V Hugh M. Smith: Cruise 12, 21°30'N., 158°26'W., October 26, 1951. Messenger time: 1439 GCT. Weather: 00, cloud coverage 5. Wind: 110°, 10 kt. Sea: 3-5 ft. Wire angle: 00°. Depth of water: 1350 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.50	34.88	22.80		0.29
00					0.42 1/
10	26.50	34.96	22.87		0.31
10					0.40 1/
26	26.38	34.86	22.83		0.36
26					0.41 1/
55	26.16	34.88	22.91		0.45
55					0.35 1/
110	24.34	34.86	23.45		0.40
218	17.56	34.79	25.24		0.78
326	10.53	34.20	26.26		1.84
326					1.94 1/
438	07.58	34.14	26.68		2.73
546	06.23	34.21	26.92		3.01
546					3.14 1/
653	05.42	34.29	27.09		3.26
862	04.67	34.44	27.29		3.33
862					3.36 1/
1073	04.10	34.48	27.39		3.23
1269	03.53	34.50	27.45		2.75

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.52	34.88	22.80	0.000	1.943
10	26.50	34.96	22.86	0.050	1.893
20	26.43	34.88	22.82	0.101	1.842
30	26.35	34.86	22.83	0.151	1.792
50	26.19	34.88	22.90	0.251	1.692
75	26.00	34.88	22.96	0.375	1.568
100	25.10	34.84	23.21	0.496	1.447
150	21.95	35.03	24.27	0.707	1.236
200	18.50	34.88	25.07	0.873	1.070
250	15.88	34.62	25.50	1.012	0.931
300	12.00	34.29	26.05	1.127	0.816
400	08.27	34.13	26.57	1.305	0.638
500	06.73	34.20	26.84	1.447	0.496
600	05.77	34.23	26.99	1.568	0.375
700	05.19	34.36	27.16	1.675	0.268
800	04.82	34.42	27.25	1.770	0.173
1000	04.29	34.47	27.35	1.943	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 9

M/V Hugh M. Smith: Cruise 12, 20°46'N., 158°28'W., October 26, 1951. Messenger time: 2123 GCT. Weather: 01, cloud coverage 6. Wind: 140°, 11 kt. Sea: 1-3 ft. Wire angle: 30°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.70	34.88	22.75		0.28
09	26.61	34.88	22.77		0.30
27	26.57	34.87	22.78		0.33
52	26.40	34.87	22.83		0.26
100	23.60	34.92	23.72		0.39
192	18.80	34.91	25.02		0.64
281	11.52	34.20	26.08		1.52
281					1.57 1/
368	08.79 2/	34.14	26.50		2.25
368	08.85 2/	34.14	26.49		
458	07.36	34.20	26.76		2.83
545	06.02	34.23	26.96		3.15
722	04.96	34.42	27.24		3.39
904	04.38	34.47	27.35		3.27
1097	03.84	34.47	27.40		3.40
1097					3.34 1/

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.68	34.88	22.75	0.000	1.875
10	26.61	34.88	22.77	0.051	1.824
20	26.59	34.88	22.77	0.102	1.773
30	26.56	34.87	22.78	0.153	1.722
50	26.41	34.87	22.82	0.254	1.621
75	26.00	34.86	22.94	0.380	1.495
100	23.60	34.92	23.71	0.494	1.381
150	21.15	35.03	24.49	0.687	1.188
200	18.19	34.85	25.12	0.848	1.027
250	14.73	34.47	25.64	0.981	0.894
300	10.65	34.17	26.21	1.089	0.786
400	08.24	34.14	26.58	1.260	0.615
500	06.69	34.22	26.86	1.399	0.476
600	05.56	34.29	27.06	1.516	0.359
700	05.06	34.40	27.21	1.617	0.258
800	04.69	34.45	27.29	1.708	0.167
1000	04.09	34.47	27.37	1.875	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

2/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

STATION 10

M/V Hugh M. Smith: Cruise 12, 20°18'N., 158°22'W., October 27, 1951. Messenger time: 0254 GCT. Weather: 02, cloud coverage 7. Wind: 180°, 11 kt. Sea: 1-3 ft. Wire angle: 31°. Depth of water: 2520 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.80	34.86	22.69		0.34
09	26.75	34.86	22.71		0.31
09					0.38 1/
25	26.70	34.86	22.73		0.40
25					0.33 1/
49	26.38	34.82	22.80		0.36
98	23.45	34.87	23.73		0.33
98					0.41 1/
192	18.65	34.91	25.06		0.65
281	12.01	34.25	26.02		1.44
281					1.49 1/
368	08.91 2/	34.13	26.47		2.10
368	08.98 2/	34.13	26.46		
458	07.45	34.18	26.73		2.77
546	06.24	34.25	26.95		3.16
729	05.01	34.42	27.24		3.29
915	04.34	34.46	27.34		3.19
1105	03.74	34.43	27.38		3.24

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D 1000 - \Delta D$ (dyn. m)
00	26.83	34.86	22.68	0.000	1.873
10	26.74	34.86	22.71	0.052	1.821
20	26.71	34.86	22.72	0.103	1.770
30	26.68	34.86	22.73	0.154	1.719
50	26.35	34.82	22.80	0.257	1.616
75	24.99	34.83	23.23	0.379	1.494
100	23.38	34.88	23.75	0.489	1.384
150	21.08	35.03	24.51	0.681	1.192
200	18.00	34.84	25.16	0.840	1.033
250	14.10	34.42	25.73	0.970	0.903
300	11.00	34.19	26.16	1.077	0.796
400	08.39	34.14	26.56	1.251	0.622
500	06.82	34.21	26.84	1.393	0.480
600	05.83	34.32	27.05	1.512	0.361
700	05.19	34.40	27.19	1.614	0.259
800	04.67	34.46	27.30	1.705	0.168
1000	04.12	34.46	27.36	1.873	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

2/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

STATION 11

M/V Hugh M. Smith: Cruise 12, 18°47'N., 157°27'W., October 27, 1951. Messenger time: 1724 GCT. Weather: 00, cloud coverage 6. Wind: 160°, 19 kt. Sea: 5-8 ft. Wire angle: 00°. Depth of water: 2450 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.50	34.79	22.74		0.18
10	26.49	34.78	22.74		0.27
30	26.26	34.83	22.84		0.21
59	26.06	34.79	22.88		0.34
119	22.74	35.00	24.03		0.30
237	14.22	34.36	25.66		1.04
353	08.89	34.19	26.52		2.22
466	07.75	34.30	26.78		2.71
583	06.68	34.35	26.97		2.98
695	05.78	34.37	27.10		3.14
924	04.61	34.42	27.28		3.12
1142	03.92	34.50	27.42		3.04
1352	03.28	34.52	27.50		3.02

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.50	34.79	22.73	0.000	1.901
10	26.49	34.78	22.73	0.051	1.850
20	26.39	34.80	22.78	0.102	1.799
30	26.26	34.83	22.84	0.153	1.748
50	26.11	34.80	22.86	0.254	1.647
75	25.52	34.81	23.06	0.377	1.524
100	23.68	34.91	23.68	0.491	1.410
150	21.80	35.11	24.37	0.687	1.214
200	18.50	34.90	25.09	0.851	1.050
250	13.32	34.31	25.81	0.982	0.919
300	10.05	34.18	26.32	1.082	0.819
400	08.40	34.23	26.62	1.245	0.656
500	07.41	34.33	26.85	1.384	0.517
600	06.52	34.35	26.99	1.506	0.395
700	05.74	34.37	27.10	1.617	0.284
800	05.19	34.39	27.19	1.718	0.183
1000	04.36	34.45	27.33	1.901	0.000

STATION 12

M/V Hugh M. Smith: Cruise 12, 19°28'N., 157°27'W., October 28, 1951. Messenger time: 0037 GCT. Weather: 00, cloud coverage 9. Wind: 180°, 18 kt. Sea: 5-8 ft. Wire angle: 07°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.10	34.86	22.92		0.28
10	26.10	34.87	22.93		0.30
10					0.35 1/
31	26.08	34.86	22.92		0.31
31					0.36 1/
61	24.54	34.89	23.41		0.27
61					0.38 1/
119	21.78	35.12	24.39		0.34
119					0.39 1/
234	13.58	34.33	25.78		1.22
346	08.81	34.17	26.52		2.25
346					2.34 1/
453	06.87	34.22	26.84		2.93
453					2.88 1/
564	06.12	34.34	27.04		3.13
564					3.19 1/
673	05.59	34.35	27.11		3.26
673					3.21 1/
894	04.66	34.49	27.33		3.24
1107	03.96	34.43	27.36		3.22
1107					3.14 1/
1314	03.36	34.59	27.54		1.79

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.10	34.86	22.91	0.000	1.774
10	26.10	34.87	22.92	0.050	1.724
20	26.10	34.87	22.92	0.099	1.675
30	26.08	34.86	22.92	0.149	1.625
50	25.60	34.88	23.08	0.246	1.528
75	23.89	34.90	23.61	0.360	1.414
100	22.78	35.00	24.01	0.463	1.311
150	19.55	35.03	24.92	0.639	1.135
200	15.46	34.52	25.51	0.780	0.994
250	12.78	34.26	25.88	0.898	0.876
300	10.40	34.16	26.24	0.999	0.775
400	07.53	34.19	26.72	1.161	0.613
500	06.46	34.32	26.97	1.288	0.486
600	05.88	34.35	27.07	1.400	0.374
700	05.47	34.37	27.14	1.504	0.270
800	05.01	34.46	27.26	1.600	0.174
1000	04.34	34.46	27.34	1.774	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 13

M/V Hugh M. Smith: Cruise 12, 20°06'N., 157°28'W., October 28, 1951. Messenger time: 0747 GCT. Weather: 00, cloud coverage not recorded. Wind: 150°, 19 kt. Sea: 5-8 ft. Wire angle: 09°. Depth of water: 2260 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.10	34.85	22.90		0.18
09	26.12	34.85	22.90		0.21
28	26.13	34.84	22.89		0.23
55	26.02	34.85	22.93		0.24
111	22.82	34.93	23.96		0.36
214	17.18	34.75	25.30		0.48
314	10.58	34.17	26.22		1.77
412	07.98	34.19	26.66		2.55
412					2.53 1/
513	06.60	34.24	26.90		2.95
611	06.18	34.36	27.05		3.07
611					3.12 1/
812	04.92	34.46	27.28		3.17
1010	04.30	34.48	27.36		3.13
1207	03.64	34.50	27.45		3.16

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.12	34.85	22.90	0.000	1.881
10	26.12	34.85	22.90	0.050	1.831
20	26.13	34.84	22.89	0.099	1.782
30	26.13	34.84	22.89	0.149	1.732
50	26.07	34.85	22.91	0.249	1.632
75	25.37	34.86	23.14	0.371	1.510
100	23.25	34.91	23.81	0.482	1.399
150	21.50	35.08	24.43	0.674	1.207
200	18.20	34.88	25.14	0.835	1.046
250	14.10	34.37	25.69	0.967	0.914
300	11.11	34.19	26.14	1.075	0.806
400	08.22	34.18	26.61	1.247	0.634
500	06.70	34.23	26.87	1.385	0.496
600	06.27	34.34	27.01	1.505	0.376
700	05.62	34.38	27.13	1.613	0.268
800	04.99	34.45	27.26	1.709	0.172
1000	04.31	34.49	27.36	1.881	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 14

M/V Hugh M. Smith: Cruise 12, 20°40'N., 157°28'W., October 28, 1951. Messenger time: 1451 GCT. Weather: 00, cloud coverage not recorded. Wind: 140°, 16 kt. Sea: 3-5 ft. Wire angle: 00°. Depth of water: 2150 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	34.86	22.88		0.24
10	26.18	34.86	22.89		0.26
30	26.21	34.86	22.88		0.29
60	25.63	34.87	23.07		0.31
60					0.36 1/
120	20.56	34.99	24.62		0.40
120					0.46 1/
239	14.60	34.43	25.64		1.05
355	09.85	34.14	26.32		1.95
355					1.86 1/
469	07.20	34.19	26.78		2.73
585	05.92	34.26	27.00		3.03
697	05.46	34.35	27.13		3.15
926	04.46	34.43	27.31		3.15
1147	03.84	34.46	27.39		3.10
1357	03.29	34.50	27.48		3.09

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.22	34.86	22.88	0.000	1.867
10	26.18	34.86	22.89	0.050	1.817
20	26.19	34.86	22.88	0.100	1.767
30	26.21	34.86	22.88	0.150	1.717
50	25.88	34.86	22.98	0.249	1.618
75	25.20	34.86	23.19	0.369	1.498
100	23.30	34.90	23.79	0.480	1.387
150	18.98	34.90	24.96	0.660	1.207
200	16.70	34.68	25.35	0.803	1.064
250	13.98	34.39	25.73	0.929	0.938
300	11.68	34.22	26.06	1.038	0.829
400	08.63	34.13	26.51	1.219	0.648
500	06.73	34.20	26.84	1.363	0.504
600	05.85	34.27	27.01	1.484	0.383
700	05.45	34.35	27.12	1.592	0.275
800	04.98	34.40	27.22	1.690	0.177
1000	04.19	34.45	27.35	1.867	0.000

1/ Values do not agree within ± 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 15

M/V Hugh M. Smith: Cruise 12, 21°05'N., 157°28'W., October 28, 1951. Messenger time: 1925 GCT. Weather: 01, cloud coverage 4. Wind: 140°, 16 kt. Sea: 3-5 ft. Wire angle: 00°. Depth of water: 30 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	34.89	22.91		0.37
10	26.18	34.87	22.90		0.36
26	26.12	34.88	22.93		0.35
35	26.08	34.88	22.94		0.37

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.20	34.89			
10	26.18	34.87			
20	26.13	34.88			
30	26.09	34.88			

STATION 16

M/V Hugh M. Smith: Cruise 12, 21°17'N., 157°25'W., October 28, 1951. Messenger time: 2231 GCT. Weather: 01, cloud coverage 4. Wind: 140°, 16 kt. Sea: 3-5 ft. Wire angle: 09°. Depth of water: 300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.10	34.79	22.87		0.30
10	26.04	34.84	22.92		0.30
25	25.92	34.82	22.95		0.32
49	25.78	34.85	23.01		0.35
98	23.18	35.01	23.91		0.41
98					0.36 2/
196	18.47	34.88	25.08		0.60
292	10.98	34.16	26.15		1.49
389	08.23 1/	34.12	26.57		2.16
389	08.29 1/	34.12	26.56		
487	06.71	34.21	26.86		2.63

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD1000 - ΔD (dyn. m)
00	26.07	34.79			
10	26.04	34.84			
20	25.97	34.82			
30	25.88	34.82			
50	25.77	34.85			
75	24.08	34.93			
100	22.96	35.04			
150	20.60	35.14			
200	18.28	34.87			
250	14.05	34.39			
300	10.65	34.14			
400	08.12	34.12			
500	06.58	34.21			

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

2/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 17

M/V Hugh M. Smith: Cruise 12, 21°48'N., 157°29'W., October 29, 1951. Messenger time: 0535 GCT. Weather: 00, cloud coverage 8. Wind: 140°, 16 kt. Sea: 3-5 ft. Wire angle: 23°. Depth of water: 1900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.80	34.81	22.96		0.36
09	25.84	34.79	22.94		0.34
27	25.67	34.79	23.00		0.39
54	25.66	34.85	23.05		0.48
105	22.89	34.98	23.97		0.41
203	19.71	35.18	24.99		0.49
295	11.68	34.20	26.05		1.30
383	09.02 1/	34.09	26.42		2.05
383	09.08 1/	34.09	26.41		2.01
476	07.10	34.10	26.72		2.72
565	06.04	34.18	26.92		3.02
755	04.95	34.34	27.18		3.23
946	04.29	34.46	27.35		3.08
1145	03.76	34.42	27.37		3.11
1145					3.07 1/

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.83	34.81	22.96	0.000	1.918
10	25.84	34.79	22.94	0.049	1.869
20	25.73	34.79	22.98	0.098	1.820
30	25.65	34.79	23.00	0.147	1.771
50	25.67	34.84	23.03	0.245	1.673
75	25.25	34.87	23.18	0.364	1.554
100	23.07	34.96	23.90	0.474	1.444
150	21.55	35.23	24.53	0.662	1.256
200	19.82	35.19	24.97	0.825	1.093
250	16.00	34.62	25.47	0.966	0.952
300	11.40	34.18	26.08	1.081	0.837
400	08.67	34.08	26.47	1.264	0.654
500	06.71	34.13	26.79	1.412	0.506
600	05.79	34.21	26.97	1.537	0.381
700	05.21	34.30	27.11	1.647	0.271
800	04.73	34.40	27.25	1.745	0.173
1000	04.19	34.46	27.35	1.918	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

2/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 18

M/V Hugh M. Smith: Cruise 12, 22°12'N., 157°31'W., October 29, 1951. Messenger time: 0900 GCT. Weather: 00, cloud coverage 3. Wind: 130°, 12 kt. Sea: 5-8 ft. Wire angle: 24°. Depth of water: 2560 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.70	34.67	22.89		0.35
00					0.40 1/
09	25.72	34.68	22.90		0.32
27	25.56	34.75	23.00		0.30
27					0.39 1/
54	25.56	34.74	22.99		0.33
107	22.46	34.95	24.07		0.38
107					0.47 1/
209	18.86	35.01	25.09		0.44
307	12.20	34.16	25.92		1.29
307					1.34 1/
402	08.74	34.10	26.47		2.06
402					2.10 1/
501	06.49	34.05	26.76		2.62
597	05.71	34.13	26.92		3.03
800	04.67	34.34	27.21		3.19
1013	03.97	34.48	27.40		3.03
1229	03.40	34.39	27.38		2.92

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.73	34.67	22.88	0.000	1.938
10	25.72	34.68	22.90	0.050	1.888
20	25.62	34.73	22.96	0.099	1.839
30	25.55	34.75	23.00	0.148	1.790
50	25.55	34.74	22.99	0.246	1.692
75	25.15	34.78	23.15	0.367	1.571
100	22.96	34.90	23.88	0.477	1.461
150	21.12	35.20	24.63	0.663	1.275
200	19.20	35.06	25.03	0.822	1.116
250	15.50	34.52	25.51	0.961	0.977
300	12.50	34.19	25.88	1.080	0.858
400	08.85	34.10	26.45	1.273	0.665
500	06.49	34.05	26.76	1.424	0.514
600	05.68	34.14	26.93	1.552	0.386
700	05.14	34.24	27.07	1.665	0.273
800	04.67	34.35	27.21	1.766	0.172
1000	03.98	34.48	27.39	1.938	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 19

M/V Hugh M. Smith: Cruise 12, 21°50'N., 156°47'W., October 29, 1951. Messenger time: 1655 GCT. Weather: 00, cloud coverage 10. Wind: 190°, 13 kt. Sea: 5-8 ft. Wire angle: 08°. Depth of water: 2680 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.70	34.78	22.97		0.33
10	25.73	34.81	22.99		0.34
30	25.75	34.82	22.99		0.31
60	25.75	34.81	22.99		0.47
119	22.53	35.02	24.10		0.41
235	18.00	34.88	25.20		0.56
348	09.96	34.07	26.25		1.70
458	07.88	34.17	26.66		2.61
571	06.33	34.23	26.92		3.08
681	05.24	34.29	27.10		3.23
906	04.61	34.42	27.28		3.22
1124	04.00	34.45	27.38		3.19
1338	03.34	34.51	27.48		3.07
1338					3.12 1/

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.73	34.78	22.97	0.000	1.951
10	25.73	34.81	22.99	0.049	1.902
20	25.74	34.82	22.99	0.098	1.853
30	25.75	34.82	22.99	0.147	1.804
50	25.75	34.81	22.98	0.245	1.706
75	25.73	34.83	23.01	0.367	1.584
100	23.65	34.92	23.70	0.481	1.470
150	21.46	35.19	24.53	0.674	1.277
200	19.40	35.11	25.02	0.836	1.115
250	16.95	34.73	25.33	0.979	0.972
300	11.70	34.14	25.99	1.100	0.851
400	08.86	34.11	26.46	1.287	0.664
500	07.23	34.20	26.77	1.437	0.514
600	05.96	34.24	26.97	1.563	0.388
700	05.16	34.30	27.12	1.673	0.278
800	04.87	34.38	27.22	1.771	0.180
1000	04.41	34.45	27.32	1.951	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 20

M/V Hugh M. Smith: Cruise 12, 21°10'N., 156°35'W., October 29, 1951. Messenger time: 2334 GCT. Weather: 00, cloud coverage 10. Wind: 150°, 8 kt. Sea: 1-3 ft. Wire angle: 02°. Depth of water: 256 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.70	34.84	23.03		0.27
10	25.70	34.84	23.03		0.28
25	25.72	34.84	23.02		0.36
50	25.72	34.87	23.04		0.36
101	22.44	35.00	24.11		0.39
201	17.31	34.76	25.27		0.54
300	11.20	34.14	26.09		1.34

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.72	34.84			
10	25.70	34.84			
20	25.71	34.84			
30	25.72	34.84			
50	25.72	34.87			
75	25.65	34.88			
100	22.44	35.00			
150	20.37	35.18			
200	17.32	34.78			
250	12.63	34.24			
300	11.20	34.14			

STATION 21

M/V Hugh M. Smith: Cruise 12, 20°49'N., 156°45'W., October 30, 1951. Messenger time: 0337 GCT. Weather: 00, cloud coverage 10. Wind: direction not recorded, 14 kt. Sea: 1-3 ft. Wire angle: 00°. Depth of water: 35 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.80	34.58	22.79		0.40
10	25.84	34.81	22.96		0.39
25	25.48	34.82	23.08		0.49

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.82	34.58			
10	25.84	34.81			
20	25.66	34.82			
30	25.35	34.82			

STATION 22

M/V Hugh M. Smith: Cruise 12, 20°22'N., 156°39'W., October 30, 1951. Messenger time: 0808 GCT. Weather: 00, cloud coverage 10. Wind: 070°, 22 kt. Sea: 1-3 ft. Wire angle: 26°. Depth of water: 1220 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.50	34.75	22.71		0.33
09	26.48	34.75	22.72		0.34
27	26.50	34.83	22.77		0.35
55	25.86	34.82	22.96		0.32
108	22.95	35.06	24.02		0.34
211	18.76	34.89	25.02		0.50
313	10.41	34.15	26.24		1.82
406	08.54	34.21	26.60		2.45
506	07.06	34.24	26.83		2.94
601	06.08	34.32	27.03		3.13
800	05.05	34.40	27.22		3.13
1002	04.16	34.45	27.36		3.06
1207	03.62	34.43	27.39		3.06

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.49	34.75	22.71	0.000	1.906
10	26.48	34.75	22.71	0.051	1.855
20	26.50	34.80	22.74	0.103	1.803
30	26.49	34.83	22.77	0.154	1.752
50	26.26	34.84	22.85	0.255	1.651
75	25.45	34.85	23.11	0.378	1.528
100	23.65	34.98	23.75	0.491	1.415
150	21.15	35.18	24.60	0.680	1.226
200	19.41	34.98	24.91	0.843	1.063
250	14.20	34.40	25.70	0.980	0.926
300	10.77	34.16	26.18	1.087	0.819
400	08.65	34.21	26.57	1.260	0.646
500	07.14	34.24	26.82	1.402	0.504
600	06.08	34.32	27.02	1.524	0.382
700	05.50	34.37	27.13	1.631	0.275
800	05.05	34.41	27.22	1.730	0.176
1000	04.16	34.46	27.36	1.906	0.000

STATION 23

M/V Hugh M. Smith: Cruise 12, 19°44'N., 156°44'W., October 30, 1951. Messenger time: first cast 1453 GCT, second cast 1553 GCT. Weather: not recorded, cloud coverage 8. Wind: 220°, 16 kt. Sea: 1-3 ft. Wire angle: first cast 48°, second cast 62°. Depth of water: 2525 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.10	34.86	22.91		0.25
07	26.12	34.83	22.89		0.31
19	26.14	34.83	22.88		0.29
36	25.37	34.86	23.14		0.28
68	23.21	34.97	23.87		0.35
129	19.74	35.12	24.94		0.46
183	16.33	34.63	25.41		0.72
233	13.58	34.32	25.77		1.30
282	10.52	34.14	26.21		1.85
325	09.02	34.18	26.49		2.21
424	07.04	34.19	26.80		2.82
514	06.40	34.34	27.00		2.87
645	05.80	34.38	27.11		3.10
633	05.71	34.43	27.16		2.87
912	04.49	34.31	27.21		3.18

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.13	34.86	22.90	0.000	1.731
10	26.13	34.83	22.88	0.050	1.681
20	26.13	34.83	22.88	0.100	1.631
30	26.01	34.84	22.93	0.149	1.582
50	24.00	34.92	23.60	0.242	1.489
75	22.90	35.01	23.99	0.346	1.385
100	21.53	35.22	24.53	0.438	1.293
150	18.72	34.96	25.08	0.598	1.133
200	15.23	34.50	25.55	0.734	0.997
250	12.60	34.24	25.90	0.850	0.881
300	09.80	34.14	26.33	0.949	0.782
400	07.35	34.19	26.75	1.105	0.626
500	06.50	34.34	26.98	1.230	0.501
600	06.03	34.36	27.06	1.342	0.389
700	05.37	34.42	27.19	1.445	0.286
800	04.91	34.36	27.20	1.541	0.190
1000	04.20	34.31	27.23	1.731	0.000

STATION 24

M/V Hugh M. Smith: Cruise 12, 19°04'N., 156°38'W., October 31, 1951. Messenger time: 0042 GCT. Weather: not recorded, cloud coverage 7. Wind: 160°, 13 kt. Sea: 1-3 ft. Wire angle: 32°. Depth of water: 2580 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.40	34.78	22.77		0.28
09	26.28	34.77	22.79		0.26
25	26.08	34.79	22.87		0.31
49	25.23	34.86	23.19		0.26
97	22.56	34.98	24.06		0.33
187	16.08	34.61	25.45		0.68
277	10.04	34.13	26.29		1.77
363	08.55 1/	34.28	26.64		2.66
363	08.61 1/	34.28	26.63		
453	07.38	34.35	26.87		3.00
540	06.69	34.38	27.00		3.08
726	05.51	34.42	27.18		3.22
917	04.64	34.45	27.30		3.09
1115	04.00	34.47	27.39		3.12

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.36	34.78	22.77	0.000	1.757
10	26.27	34.77	22.79	0.051	1.706
20	26.12	34.78	22.85	0.101	1.656
30	26.00	34.80	22.90	0.151	1.606
50	25.22	34.86	23.18	0.248	1.509
75	23.82	34.92	23.65	0.361	1.396
100	22.15	35.05	24.23	0.461	1.296
150	19.07	35.03	25.04	0.628	1.129
200	14.23	34.39	25.68	0.762	0.995
250	11.40	34.16	26.06	0.871	0.886
300	09.62	34.16	26.38	0.965	0.792
400	08.06	34.31	26.74	1.119	0.638
500	07.97	34.37	26.80	1.255	0.502
600	06.30	34.40	27.06	1.377	0.380
700	05.62	34.42	27.16	1.481	0.276
800	05.17	34.43	27.22	1.578	0.179
1000	04.32	34.46	27.34	1.757	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

STATION 25

M/V Hugh M. Smith: Cruise 12, 18°21'N., 156°38'W., October 31, 1951. Messenger time: 0742 GCT. Weather: 00, cloud coverage 5. Wind: 220°, 6 kt. Sea: not recorded. Wire angle: 00°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.30	34.78	22.80		0.28
10	26.25	34.77	22.80		0.29
25	26.16	34.81	22.86		0.29
55	26.18	34.82	22.86		0.35
110	25.03	34.80	23.20		0.36
219	16.13	34.44	25.31		0.98
328	09.40	34.22	26.46		2.25
441	07.38	34.20	26.76		2.74
548	06.42	34.32	26.98		3.08
655	05.80	34.41	27.13		3.10
866	04.86	34.43	27.26		3.20
1076	04.04	34.49	27.40		3.16
1277	03.46	34.51	27.47		3.16

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.28	34.78	22.80	0.000	1.904
10	26.25	34.77	22.80	0.051	1.853
20	26.19	34.80	22.84	0.101	1.803
30	26.13	34.81	22.87	0.151	1.753
50	26.17	34.82	22.86	0.252	1.652
75	26.07	34.82	22.89	0.377	1.527
100	25.68	34.81	23.01	0.501	1.403
150	21.43	35.00	24.39	0.713	1.191
200	18.42	34.75	24.99	0.879	1.025
250	13.21	34.30	25.82	1.011	0.893
300	10.40	34.24	26.31	1.112	0.792
400	07.99	34.20	26.66	1.274	0.630
500	06.78	34.24	26.87	1.409	0.495
600	06.12	34.38	27.06	1.527	0.377
700	05.56	34.42	27.17	1.630	0.274
800	05.11	34.43	27.23	1.727	0.177
1000	04.40	34.47	27.34	1.904	0.000

STATION 26

M/V Hugh M. Smith: Cruise 12, 18°03'N., 155°33'W., October 31, 1951. Messenger time: 1700 GCT. Weather: 00, cloud coverage 5. Wind: 110°, 12 kt. Sea: 1-3 ft. Wire angle: 00°. Depth of water: 2625 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.60	1/			0.34
10	25.84	34.69	22.87		0.35
10					0.41 2/
25	25.84	34.71	22.88		0.40
55	25.77	34.84	23.00		0.39
109	21.94	34.97	24.23		0.40
217	13.93	34.27	25.66		1.43
324	09.01	34.12	26.45		2.16
437	07.68 3/	34.34	26.82		2.96
437	07.72 3/	34.34	26.82		
544	06.70	34.39	27.00		3.14
652	05.88	34.42	27.13		3.23
864	04.83	34.47	27.30		3.28
864					3.33
1079	03.96	34.49	27.41		3.18
1288	03.39	34.55	27.50		3.14

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D 1000 - \Delta D$ (dyn. m)
00	25.64	34.69	22.93	0.000	1.794
10	25.84	34.69	22.87	0.050	1.744
20	25.84	34.70	22.87	0.100	1.694
30	25.84	34.73	22.90	0.150	1.644
50	25.79	34.83	22.99	0.248	1.546
75	25.62	34.85	23.05	0.370	1.424
100	22.32	34.94	24.10	0.479	1.315
150	20.55	34.99	24.62	0.660	1.134
200	15.60	34.40	25.39	0.811	0.983
250	11.31	34.12	26.05	0.927	0.867
300	09.48	34.09	26.34	1.021	0.773
400	08.09	34.28	26.71	1.179	0.615
500	07.08	34.37	26.93	1.310	0.484
600	06.24	34.41	27.07	1.424	0.370
700	05.55	34.44	27.18	1.526	0.268
800	05.09	34.47	27.26	1.621	0.173
1000	04.38	34.48	27.35	1.794	0.000

1/ No sample.

2/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

3/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

STATION 27

M/V Hugh M. Smith: Cruise 12, 18°40'N., 154°28'W., November 1, 1951. Messenger time: 0255 GCT. Weather: 00, cloud coverage 5. Wind: 060°, 10 kt. Sea: 1-3 ft. Wire angle: 22°. Depth of water: 2900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.10	34.65	22.76		0.35
09	26.06	34.62	22.75		0.33
23	25.92	34.70	22.85		0.36
45	25.88	34.74	22.89		0.42
91	25.03	34.78	23.19		0.43
185	18.06	34.69	25.04		0.73
273	10.70	34.23	26.25		2.03
367	08.89 1/	34.40	26.69		2.72
367	08.95 1/	34.40	26.67		
455	07.65	34.39	26.87		2.99
548	06.80	34.42	27.01		3.11
732	05.62	34.44	27.18		3.23
916	04.74	34.45	27.29		3.19
1114	04.09	34.43	27.35		3.02

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.09	34.65	22.76	0.000	1.835
10	26.06	34.62	22.74	0.051	1.784
20	25.98	34.68	22.81	0.102	1.733
30	25.90	34.71	22.86	0.152	1.683
50	25.88	34.74	22.89	0.252	1.583
75	25.88	34.74	22.89	0.377	1.458
100	23.90	34.82	23.55	0.495	1.340
150	20.38	34.92	24.61	0.689	1.146
200	16.82	34.58	25.25	0.843	0.992
250	11.60	34.25	26.10	0.962	0.873
300	10.12	34.28	26.38	1.054	0.781
400	08.41	34.39	26.75	1.208	0.627
500	07.23	34.41	26.94	1.337	0.498
600	06.44	34.43	27.06	1.452	0.383
700	05.80	34.44	27.15	1.556	0.279
800	05.27	34.45	27.22	1.654	0.181
1000	04.44	34.44	27.31	1.835	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

STATION 28

M/V Hugh M. Smith: Cruise 12, 19°16'N., 154°32'W., November 1, 1951. Messenger time: 0849 GCT. Weather: 20, cloud coverage 10. Wind: 080°, 9 kt. Sea: 1-3 ft. Wire angle: 18°. Depth of water: 2800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.90	34.87	22.97		0.36
10	25.96	34.82	22.93		0.38
24	25.76	34.87	23.03		0.39
51	25.66	34.87	23.06		0.39
103	25.48	34.89	23.13		0.37
203	17.38	34.52	25.07		0.81
301	10.52	2/			2.47
405	07.80 1/	34.20	26.70		2.66
405	07.86 1/	34.20	26.69		2.71
505	06.80	34.24	26.87		2.95
505					3.00 3/
604	06.14	34.36	27.05		3.12
799	05.00	34.44	27.26		3.24
999	04.52	34.46	27.31		3.17
1195	03.78	34.48	27.42		3.17
1195					3.12 3/

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.94	34.87	22.97	0.000	1.896
10	25.96	34.82	22.93	0.049	1.847
20	25.82	34.87	23.01	0.098	1.798
30	25.71	34.87	23.04	0.147	1.749
50	25.66	34.87	23.06	0.244	1.652
75	25.58	34.88	23.09	0.364	1.532
100	25.50	34.88	23.11	0.484	1.412
150	21.62	34.77	24.16	0.700	1.196
200	17.50	34.53	25.05	0.870	1.026
250	12.42	34.23	25.93	0.998	0.898
300	10.52	34.20	26.25	1.097	0.799
400	07.96	34.20	26.67	1.261	0.635
500	06.84	34.23	26.85	1.397	0.499
600	06.18	34.36	27.04	1.517	0.379
700	05.59	34.41	27.15	1.622	0.274
800	05.00	34.44	27.25	1.718	0.178
1000	04.51	34.46	27.32	1.896	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

2/ No sample.

3/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

STATION 29

M/V Hugh M. Smith: Cruise 12, 20°04'N., 154°33'W., November 1, 1951. Messenger time: 1532 GCT. Weather: 00, cloud coverage 4. Wind: 080°, 6 kt. Sea: 1-3 ft. Wire angle: 08°. Depth of water: 3000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.40	34.48	22.83		0.25
10	25.45	34.46	22.82		0.24
25	25.54	34.52	22.83		0.28
54	25.62	34.77	23.00		0.33
108	21.96	34.79	24.09		0.33
213	15.08	34.37	25.49		1.06 1/
213					1.11
318	09.85	34.14	26.33		1.86
426	08.10 2/	3/			2.64
426	08.16 2/				
529	06.31	34.22	26.92		2.93
633	05.39	34.29	27.09		3.04
837	04.83	34.42	27.26		3.16
1042	04.13	34.44	27.35		3.03
1240	03.55	34.50	27.45		3.11

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.44	34.48	22.83	0.000	1.840
10	25.45	34.46	22.81	0.050	1.790
20	25.52	34.48	22.81	0.101	1.739
30	25.58	34.57	22.86	0.151	1.689
50	25.62	34.76	22.99	0.251	1.589
75	24.00	34.80	23.51	0.367	1.473
100	22.66	34.79	23.89	0.473	1.367
150	19.55	34.71	24.67	0.658	1.182
200	16.50	34.46	25.23	0.811	1.029
250	12.47	34.19	25.88	0.935	0.905
300	10.21	34.14	26.26	1.036	0.804
400	08.54	34.17	26.56	1.205	0.635
500	06.75	34.20	26.84	1.347	0.493
600	05.64	34.27	27.04	1.466	0.374
700	05.08	34.40	27.21	1.569	0.271
800	04.88	34.42	27.25	1.662	0.178
1000	04.37	34.43	27.31	1.840	0.000

1/ Values do not agree within 0.02 µg at/l tolerance. Average value used in constructing phosphate-temperature curve.

2/ Values do not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

3/ No sample.

STATION 30

M/V Hugh M. Smith: Cruise 12, 20°38'N., 154°28'W., November 1, 1951. Messenger time: 2106 GCT. Weather: 00, cloud coverage 5. Wind: 080°, 9 kt. Sea: 1-3 ft. Wire angle: 19°. Depth of water: no data.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.70	34.62	22.85		0.19
09	25.71	34.66	22.89		0.23
23	25.75	34.73	22.93		0.31
52	25.71	34.86	23.04		0.25
101	23.18	34.75	23.71		0.33
198	16.09	34.43	25.31		0.88
297	10.86	34.11	26.13		1.54
398	08.91 1/	34.25	26.56		2.53
398	08.97 1/	34.25	26.55		
495	07.20	34.30	26.86		2.90
594	06.39	34.32	26.99		3.02
788	05.24	34.35	27.15		3.16
989	04.43	34.42	27.30		3.04
1191	03.72	34.47	27.41		3.10

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.73	34.62	22.85	0.000	1.895
10	25.71	34.67	22.89	0.050	1.845
20	25.74	34.72	22.92	0.100	1.795
30	25.74	34.77	22.96	0.149	1.746
50	25.72	34.86	23.03	0.247	1.648
75	25.62	34.87	23.07	0.368	1.527
100	23.50	34.76	23.62	0.482	1.413
150	19.62	34.70	24.65	0.674	1.221
200	15.95	34.43	25.33	0.825	1.070
250	12.55	34.19	25.87	0.948	0.947
300	10.80	34.11	26.13	1.051	0.844
400	08.90	34.25	26.56	1.227	0.668
500	07.16	34.30	26.86	1.368	0.527
600	06.35	34.32	26.99	1.489	0.406
700	05.78	34.33	27.07	1.601	0.294
800	05.21	34.35	27.15	1.706	0.189
1000	04.40	34.42	27.30	1.895	0.000

1/ Thermometers did not agree within 0.02°C tolerance. Average value used in constructing temperature-depth curve.

Equator with the area used by
t American fishery off Mexico
l America (which supports a
00 industry) indicates a likeli-
ull utilization of the tunas from
l Pacific would produce a like

eve that there are other regions
opical and subtropical Pacific
ch, because of unique oceano-
onditions, will prove unusually
of fish. For example, islands
from the bottom of the ocean and
ng the flow of major currents
cause enrichment of surround-
ce waters. Also, north of the
Islands at the boundary between
rly-flowing North Pacific Drift
esterly-flowing North Equatorial
is a region of turbulence and
ich shows promise of prodigious
productivity. Investigations are
r way to find and chart these
environments and to evaluate
ntial fishery resources.

—

15838

DIVIDENDS FROM RESEARCH

THE BIRTH OF A FISHERY

Donald L. McKernan
U. S. Fish and Wildlife Service
Honolulu, Hawaii

Organized as the Pacific Oceanic Fishery Investigations, a unit of the U. S. Fish and Wildlife Service with headquarters in Honolulu, we have been investigating the potential fishery resources of the central Pacific, an area of nearly 7 million square miles, from approximately 30° N. to 10° S. latitude and from 110° W. longitude to 180°. Our efforts have been concentrated on locating pelagic, oceanic areas with favorable conditions for biological productivity and systematically searching such areas for concentrations of fish.

Two research methods are being used to attain those objectives. First, we have depended upon biological and physical oceanography to define the regions of potential productivity. The movement of major water masses, including current boundaries, vertical motion, and measures of inorganic nutrient salts in the sea--all have provided clues to areas of high biological productivity. Second, after finding promising environments in the open sea, we have sampled the fish populations, using accepted commercial fishing techniques as well as the biological sampling methods necessary for capturing the smaller, more elusive fishes.

Using these methods, we have found evidences of upwelling associated with a divergence at or near the Equator about 1,200 miles south of Hawaii. This upwelling enriches the euphotic zone by bringing up inorganic salts from the deeper waters. Plankton and midwater trawl samples, when compared with similar samples from other pelagic tropical waters, co unusually large amounts of organi Experimental fishing by various m demonstrated the existence of an ex sive concentration of yellowfin tuna, center of abundance lying in a band f about 140° to 170° W. longitude and f 5° N. latitude to the Equator, an are about 500,000 square miles.

Though we find the longline metho fishing successful for sampling yellow only an occasional skipjack is taken this gear; however, our studies of t eggs and larvae convince us that, in ad tion to the abundant yellowfin, skipj are present in even greater numbers.

We are now encouraging the devel ment of a commercial fishery. This p spring two West Coast fishing boats t 210 tons of yellowfin tuna from the L Islands region near the Equator while ing the longline method of fishing. At t writing [August 1954] three more Paci Northwest boats are longline fishing that region. Here, the discovery and early exploration of these fishing grou are nearing an end and the birth of a n fishery is in progress. The success failure of this new fishery will depend whether or not American fishermen profitably harvest the tuna in the new a while using an unfamiliar type of gear, Japanese longline. The gap between completion of successful research and firm establishment of a profitable co mercial fishery is difficult to bridge; will be interesting to see whether the ce tral Pacific tuna fishery will provide of the rare examples where this transit has been successfully effected.

Although the potential yield from t newly discovered resource is unknown, comparison of the area of this vast b

A Summary of Sightings of Fish Schools and Bird Flocks and of Trolling in the Central Pacific

SPECIAL SCIENTIFIC REPORT---FISHERIES No. 154

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Explanatory Note

The series embodies results of investigations, usually of restrict
scope, intended to aid or direct management or utilization practices a
as guides for administrative or legislative action. It is issued in limi
quantities for the official use of Federal, State or cooperating Agencie
and in processed form for economy and to avoid delay in publication.

United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

A SUMMARY OF SIGHTINGS OF FISH SCHOOLS AND BIRD FLOCKS AND OF TROLLING IN THE CENTRAL PACIFIC

By

Garth I. Murphy and Isaac I. Ikehara
Fishery Research Biologists
Pacific Oceanic Fishery Investigations
U. S. Fish and Wildlife Service

Special Scientific Report: Fisheries No. 154

WASHINGTON: JUNE 1955

ABSTRACT

The results of 546 days of trolling and watching for bird flocks and fis schools are summarized in three categories based on distance from islands. T frequency of fish school sightings appears to be a function of the abundance birds, and was lower beyond 180 miles from land than within that range. Skip were the dominant species in the open ocean; yellowfin were more abundant nea land in most instances. There is a seasonal pattern in the frequency of sigh possibly associated with the life patterns of the birds. In island areas goo agreement was obtained between the abundance of fish schools and the abundanc plankton. In the oceanic areas the agreement was not very good. Possible re for the discrepancies are discussed.

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Frontispiece.--Several species of oceanic birds over a school of jumping yellowfin tuna. Kingman Reef, Line Islands. May 1951. Photograph by Fred C. June.

1. The form used to record surface observations on POFI vessels. . .

2. Map of the central Pacific Ocean showing the demarcation into "island," "semioceanic," and "oceanic" provinces. . . . . .

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ere are three important types of tuna fisheries in the Pacific, two of which by finding and catching the fish on or near the surface. The third, long-shing, widely practiced by the Japanese in the western Pacific, operates by g the large deep-swimming tunas that rarely appear at the surface and are een prior to capture. On the other hand, livebait fishing and purse seining, mer important both off Japan and the Americas, and the latter important only Americas, involve locating schools of fish before capturing them. As the of the resources of these surface and deep-swimming tunas in the central ial Pacific was little known, the Pacific Oceanic Fishery Investigations has attempted to evaluate their fishery potential by studying their abundance ir relation to the oceanic circulation and productivity. This report, one of resulting from these investigations, deals with the abundance and distribu- surface schools of tuna in the central equatorial Pacific.

ecause of the vastness of the area to be explored and the small number of available for the various types of fishing and oceanographic cruises that be made, it has been possible to cover only the most promising parts of the with cruises expressly planned to locate and fish for surface schools. In o secure information from a much broader area, systematic searching for indications of tuna schools and trolling to detect the presence of fish en done routinely during all daylight runs of POFI vessels, whatever the objectives of the cruises on which they were engaged. This method of sur- essentially parallels the scouting techniques of the commercial surface es, for most schools fished by purse-seine and livebait boats are located ing the fish in the water, by noting the presence of birds and other animals to associate with tuna, or by capturing tuna on trolling lines.

his report is a biological evaluation of all the observations on surface from the inception of the program in 1950 to April 1953 with the exception observations currently accumulating from a study around the Hawaiian Islands and Otsu 1955). The results significant to commercial trolling and livebait g have already been reported (Bates 1950, Ikehara 1953) and this aspect is considered here. In essence, we summarize and interpret what was seen from idge and what was caught from the stern during 546 days when research vessels nder way through the tropical and subtropical waters of the central Pacific.

he observations on fish schools and bird flocks are arranged to furnish isons among the various island groups in the central Pacific and comparisons n the vicinity of land and the open ocean, and to estimate variations in nce associated with different periods of the year. The results of trolling ganized in the same manner as the sighting records. Finally, the resulting tes of tuna abundance around certain islands and in limited portions of the cean are compared with the standing crop of plankton, in order to investi- he hypothesis that a larger supply of basic food should be associated with er population of animals farther up the food chain.

he recording of the numbers and types of fish schools and birds seen while ssels were under way has usually been a duty of the wheel watch under the ce of the scientist in charge, and credit is due the officers and fishermen research vessels John R. Manning, Hugh M. Smith, Charles H. Gilbert, and arter vessel Cavalieri for the keen observation and the systematic recording t they saw. Surface trolling and the maintenance of appropriate records of peration have been the responsibility of the various scientific field s.

The following lists include the birds and fishes sighted or caught dur period of observation. The first vernacular names are used in this report. second, when given, are in common use in Hawaii. Birds are not dealt with fically or as family groups because it was not always possible to identify

Fish:

Yellowfin tuna - ahi - Neothunnus macropterus (Temminck and Schlegel)
Skipjack - aku - Katsuwonus pelamis (Linnaeus)
Little tunny - kawakawa - Euthynnus affinis (Cantor)
Wahoo - ono - Acanthocybium solandri (Cuvier)
Dolphin - mahimahi - Coryphaena hippurus (Linnaeus)
Black marlin - a'u - Makaira mazara (Jordan and Snyder)
Barracuda - kaku - Sphyraena sp.
Red snapper - opakapaka - Lutianus sp.
Rainbow runner - kamani - Elagatis bipinnulatus (Quoy and Gaimard)
Needlefish - Belonidae
Jack - ulua - Caranx sp.

Birds:

Terns - Fam. Sternidae
Boobies - Fam. Sulidae
Bos'n birds - Fam. Phaethontidae
Albatrosses - Fam. Diomedeidae
Frigate birds - Fam. Fregatidae
Petrels and shearwaters - Fam. Procellariidae

VISUAL OBSERVATIONS ON FISH SCHOOLS AND BIRDS

Birds are considered with fish schools because about 85 percent of all schools sighted were accompanied by birds, and were located by first sighting birds. The relation between fish and birds is probably more apparent in the tral Pacific than along continental shores because the choppy seas characteri of the subtropical Pacific nearly always preclude sighting a school of fish accompanied by birds, unless the school is within a few hundred feet of the Although the difficulty of sighting birdless fish schools may tend to overemp size the association between birds and fish schools, it has the obvious biolo basis that both birds and fish have a common prey, the feeding fish often dri small fish and squid to the surface, where they are easy prey for birds. Thu consider birds and surface schools together because they are associated in na and because they are virtually inseparable in our observations.

Observational Procedure

For the recording of sightings of birds and fish the wheel watch is prov with a daily log (fig. 1), and is occasionally assisted by someone from the s tific party except during livebait fishing and purse seining, when a scientis almost constantly on the bridge. Despite the constant effort to systematize observations, a number of irregularities occur. For example, if a fisherman records a fish school near the end of his watch, that same school might be re a second time by the man who relieves him. Also, if a fish school or bird fl crosses and recrosses the path of the vessel, that same school or flock might recorded a number of times. Another difficulty is that the observations are quantitative. That is, not all of the birds or fish actually in a given rang from the vessel are recorded, and the proportion varies among observers and u various sea conditions. Such relative errors were not specifically considere but their effect was minimized by pooling several days' observations.

1/ The term "bird flock" refers to a working flock of birds, that is, a group of birds that are feeding or searching for food more or less as a unit. Such aggregations generally consist of 10 or more birds, and may or may not a pany a school of fish. The term "fish school" refers only to instances of de ing fish in the water, with or without birds.

OCCURRENCE OF TUNA SCHOOLS, BIRDS, AND AQUATIC MAMMALS BC 1.1

Cruise Date Noon Position

from to

n Watch
d Watch
n Watch

		TIME (LST)																							
Kind (if obvious)	yellowfin																								
	skipjack																								
	little tuna																								
	unidentified																								
Size of school	small																								
	medium																								
	large																								
	undetermined																								
Est. size of fish (lbs.)																									
No birds with school																									
Size of flock	10 or less																								
	11 - 50																								
	50 or more																								
Kinds in flock	terns																								
	boobies																								
	bo'sun birds																								
	frigate birds																								
	petrels or shearwaters																								
	other																								
No tuna in evidence																									
Give number for each kind	albatross																								
	petrels or shearwaters																								
	boobies																								
	terns																								
	frigate birds																								
	bo'sun birds																								
	storm petrels																								
Give number																									
No tuna in evidence																									

JEK 4/1/54

e 1.--The form used to record surface observa-
ns on POFI vessels. This log, introduced in
nuary 1953, calls for essentially the same in-
mation as earlier editions.

Whenever possible, a positive identification was made of the fish making up the schools. Most of the identifications were made by skilled fishermen on the wheel watch, and such identifications are usually based on the type of birds working over the schools and the general behavior of the birds and fish. Generally, when a positive identification followed, the fishermen's judgement was confirmed. Positive identifications were possible only when the fish broke water near the boat, or when one or more were caught on the trolling lines. This happened so seldom that most of the records lack positive verification. However, we believe that the errors are few.

Scope and Organization of the Sightings

The fish and bird sightings were gathered from an area of approximately 8 million square miles (fig. 2). Over this area there were 546 days of observation during the period October 17, 1950, to April 4, 1953. The intensity of sampling is adequate to give a general picture of the distribution of birds and fish but in many instances is not adequate for defining seasonal and geographical variations in abundance for subareas.

Summarization of the
ngs was facilitated by classifying the observations according to rectangles
ee of latitude by 1 degree of longitude, based on the ship's noon position.
ould result in assigning an observation to a locality as much as 60 miles
ts true occurrence, because of the distance travelled during the day. This is
ttle consequence in areas far from land, where the environment changes slowly,
y cause distortion close to land. All of the observations were entered on
ards and further coded by month and year.

After coding, the observations were divided into three groups for study and
is. The "island" observations consist of those made on days during which the
osition of the ship was within a 1° square a portion of which is within 60
of land (fig. 2). A second group, termed the "semioceanic" observations, is
p of sightings made on days when the noon position of the ship was within a
are a portion of which is between 60 and 180 miles from land. The balance
ses the "oceanic" observations. It will be realized upon reference to figure
these limits are not perfectly realized because the configuration of the
shorelines necessitated a number of compromises.

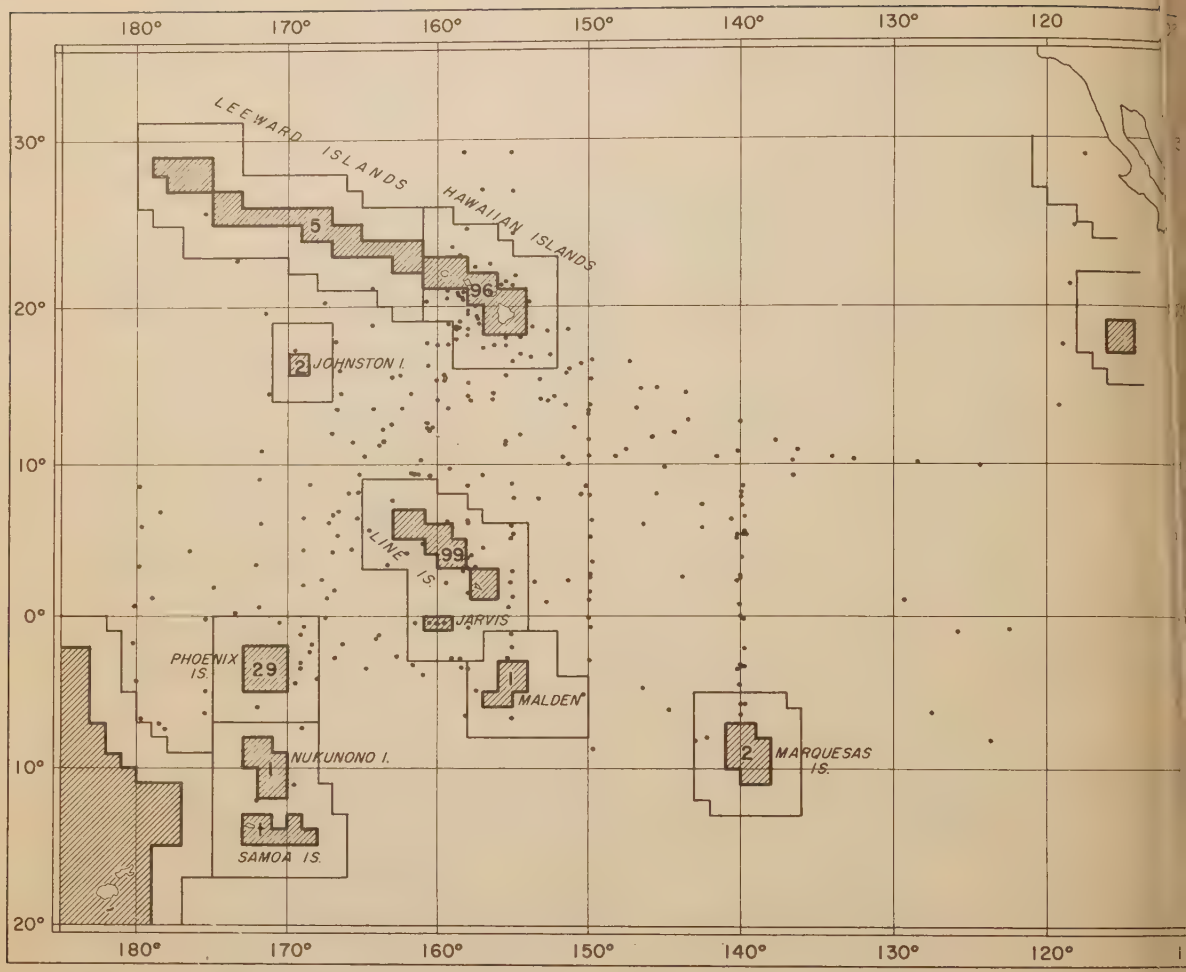


Figure 2.--Map of the central Pacific Ocean showing the demarcation into "isla "semioceanic," and "oceanic" provinces. Each dot represents the noon positi for a day's observation in the semioceanic and oceanic areas. The number of days' observations in each island area is shown by the figures.

These three groupings were made to correspond roughly with elements in the habits of the birds and the fish which might affect their occurrence. We wished ascertain whether waters in the immediate vicinity of land might not afford an e vironment of a special character, perhaps supporting denser populations of tuna than the offshore waters, for Reintjes and King (1953) have shown that the food yellowfin tuna captured near islands differs qualitatively from that of yellowfi taken in the open ocean. The semioceanic zone (60 to 180 miles from land) is be yond the immediate influence of islands, judging by the stomach contents of the yellowfin, but is within reasonable flight range for island-based birds. And fi nally, since birds are the chief indicator of fish, it was thought that some di ference in apparent abundance might be noted between the semioceanic zone and th truly oceanic areas beyond the possible daily flying range from islands, i.e., than 180 miles from land.

Island Observations

The observations from the vicinity of islands were subdivided by islands o island groups (fig. 2) and tabulated by four periods of the year roughly corres ing to the temperate-zone seasons (table 1). The Hawaiian Islands group includ Hawaii, Lanai, Molokai, Maui, Oahu, Kauai, and Niihau. The balance of the Hawa Archipelago is designated as the Leeward Islands in table 1. For the purposes this discussion the Line Islands comprise Christmas, Fanning, Palmyra, Washingt

Locality	Period	Number of days		Yellowfin		Skipjack		Mixed[1]		Unidentified		Total fish schools		Bird flocks	
		Fishing and scouting	Running	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day
Line Is.	Mar.-May	26	6	16	0.5	0	0.0	2	0.1	15	0.5	33	1.0	33	1.0
	June-Aug.	4	3	13	1.9	1	0.1	4	0.6	3	0.4	21	3.0	27	3.9
	Sept.-Nov.	22	11	20	0.6	12	0.4	4	0.1	55	1.7	91	2.8	108	3.3
	Dec.-Feb.	8	19	7	0.3	4	0.1	3	0.1	24	0.9	38	1.4	71	2.6
Total and average[2]		60	39	56	0.8	17	0.2	13	0.2	97	0.9	183	2.1	239	2.7
Phoenix Is.	Mar.-May	-	3	0	0.0	0	0.0	0	0.0	2	0.7	2	0.7	6	2.0
	June-Aug.	3	4	8	1.1	6	0.9	0	0.0	5	0.7	19	2.7	26	3.7
	Sept.-Nov.	0	2	3	1.5	2	1.0	0	0.0	2	1.0	7	3.5	1	0.5
	Dec.-Feb.	3	14	3	0.2	1	0.1	0	0.0	5	0.3	9	0.5	13	0.8
Total and average[2]		6	23	14	0.7	9	0.5	0	0.0	14	0.7	37	1.9	46	1.8
Hawaiian Is.	Mar.-May	0	9	0	0.0	7	0.8	0	0.0	7	0.8	14	1.6	18	2.0
	June-Aug.	33	15	4	0.1	81	1.7	0	0.0	20	0.4	105	2.2	100	2.1
	Sept.-Nov.	4	31	0	0.0	17	0.5	0	0.0	21	0.6	38	1.1	47	1.3
	Dec.-Feb.	0	4	1	0.2	1	0.2	0	0.0	1	0.2	3	0.8	3	0.8
Total and average[2]		37	59	5	0.1	106	0.8	0	0.0	49	0.5	160	1.4	168	1.6
Leeward Is.	Mar.-May	1	4	1	0.2	3	0.6	0	0.0	25	5.0	29	5.8	47	9.4
Jarvis I.	June-Aug.	1	0	2	2.0	0	0.0	0	0.0	1	1.0	3	3.0	4	4.0
	Dec.-Feb.	1	1	0	0.0	0	0.0	0	0.0	3	1.5	3	1.5	4	2.0
Malden I.	Sept.-Nov.	1	0	0	0.0	2	2.0	0	0.0	4	4.0	6	6.0	6	6.0
Starbuck I.	Dec.-Feb.	1	0	0	0.0	3	3.0	0	0.0	0	0.0	3	3.0	3	3.0
Johnston I.	Mar.-May	0	2	0	0.0	0	0.0	0	0.0	5	2.5	5	2.5	8	4.0
Marquesas Is.	June-Aug.	0	2	0	0.0	2	1.0	0	0.0	0	0.0	2	1.0	3	1.5
Samoa Is.	Dec.-Feb.	0	1	0	0.0	2	2.0	0	0.0	7	7.0	9	9.0	9	9.0
Nukunono Is.	Dec.-Feb.	0	1	0	0.0	0	0.0	0	0.0	1	1.0	1	1.0	1	1.0

[1] Yellowfin and skipjack.

[2] Unweighted averages.

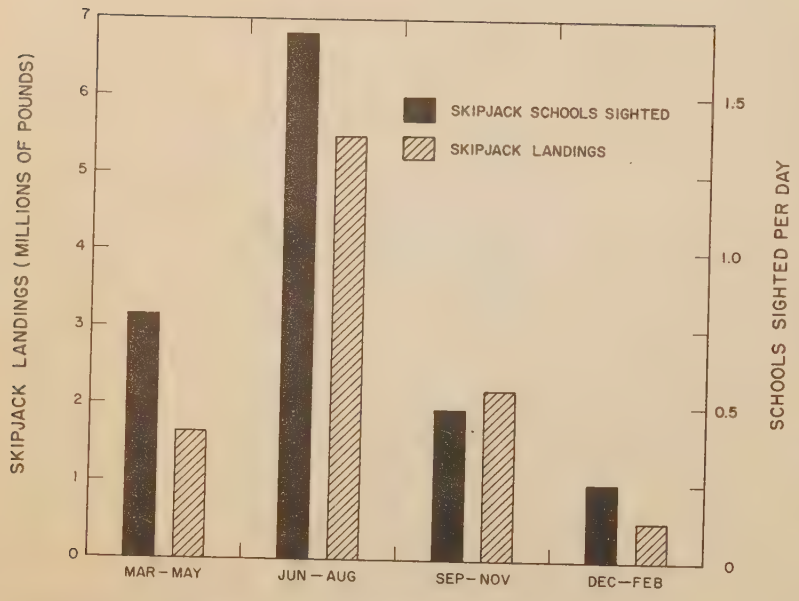


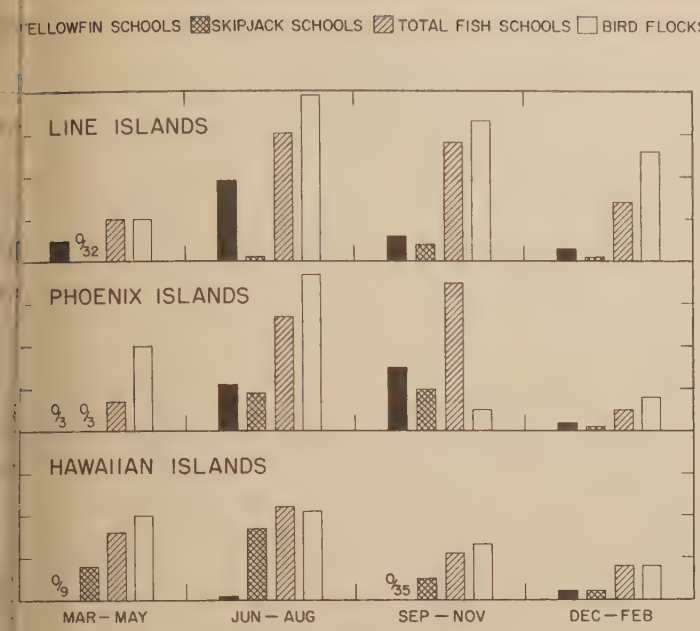
Figure 3.--Comparison between average Hawaiian skipjack landings (1950-1952) and POFI surface sightings of skipjack schools in the Hawaiian Islands area.

and Kingman Reef; the Ph
Islands are Hull, Canton
Sidney, Phoenix, Birnie,
Enderbury, Gardner, and
McKean.

For the Hawaiian Is
it is possible to examine
the reliability of sighti
as a measure of relative
abundance by comparing ou
sightings of skipjack wit
the commercial landings o
skipjack in Hawaii. The
same seasonal trends are
evident in both the sight
and landings (fig. 3). D
crepancies are minor and
cur only in the details.
For instance, commercial
landings (expressed in
pounds) treble in passing
from the March-May period
the June-August period, wh
the number of schools sigh
only doubles. Because the
fishing fleet is usually
larger in summer and the s
of skipjack is also larger
the greater increase in la
ings than in sightings is not surprising. It is clearly evident that the relativ
ly sparse surface sightings from POFI vessels furnished a description of seasonal
variation in skipjack occurrence that is very similar to the description one gets
from the catching activity of a much larger number of commercial fishing vessels.

The graphic summary of the observations made at the three principal island
groups (fig. 4) reveals a considerable difference in the species composition of t
tuna schools between the Hawaiian Islands on the one hand and the Line and Phoeni
islands on the other. The skipjack is by far the most commonly sighted tuna in th
Hawaiian Islands. This species also is by far the dominant one in the catch of th
commercial fishery (June 1951). In the Line and Phoenix islands skipjack form a
substantial part of the surface sightings, but they are considerably outnumbered b
the yellowfin (Ikehara 1953). This difference between the Line and Hawaiian islan
is also found in the populations of subsurface tunas detected by longline fishing.
In the Line Islands, where surface yellowfin are abundant, subsurface yellowfin ar
also abundant (Murphy and Shomura 1953a). In the Hawaiian Islands, where surface
yellowfin are scarce in relation to skipjack, the subsurface yellowfin are less th
one-fourth as abundant as in the Line Islands. These differences may well be caus
by differences in basic productivity or by combinations of ecological factors that
tend to favor one or the other species of tuna in each of the localities.

In contrast to the differences in species composition among the three island
areas, the general patterns of seasonal abundance are surprisingly similar (fig.
4). Each of them shows a peak in abundance of skipjack, yellowfin, and all specie
combined during the period June to November. Minor differences among island group
are to be expected in view of the small number of observations during some of the
periods in some areas. This similarity of seasonal pattern suggests that common
factors are operating in the three areas. It is difficult to suggest common fac-
tors that might affect fish abundance in all three island areas simultaneously,
since they are widely separated in space and are in different current systems.
Possibly these seasonal cycles are merely apparent changes in abundance brought
about by fluctuations in the bird populations, for, as has been shown, most fish
schools are located by birds.



e 4.--Seasonal distribution of tuna school ghtings in the Line, Phoenix, and Hawaiian lands. (Total fish schools per day includes dentified schools as well as yellowfin and pjack, table 1. The figures on the graph, h as 0/32, indicate a number of days of outing, in this case 32, during which no nools were seen.)

Semioceanic Observations

The semioceanic sightings, made between 60 and 180 miles from land, are treated somewhat differently from the island observations in that the numbers of birds sighted are listed in addition to the numbers of flocks. This was possible because the estimates of the size of the smaller flocks in the areas farther from land were reasonably accurate.

Comparison of the semioceanic fish sightings (table 2) and the island sightings (table 1) shows that yellowfin schools are more abundant close to land. In the Line and Phoenix islands yellowfin predominated near land and skipjack dominated the semioceanic zone. In the Hawaiian area all yellowfin noted were close to the islands, although skipjack predominated there as well as offshore. Thus it appears that in the central Pacific surface schools of yellowfin are rather closely associated with land; however, this is rue of the deep-swimming yellowfin (Murphy and Shomura 1953a).

Although the composition of the fish schools is different farther from land, bundance, disregarding kind, appears to be nearly as great in the semioceanic the island areas (1.3 versus 1.8 per day, tables 1 and 2). If the number of ls sighted is taken as an index, it can be concluded that the area immediately unding these small islands (0 to 60 miles from land) has about the same proivity as the outlying zone (60 to 180 miles from land), but the ecology of the s immediately around the islands favors surface schools of yellowfin tuna and of more distant waters favors schools of skipjack.

Oceanic Observations

Oceanic observations are considered to be those made farther than 180 miles land. Rather than associate them with any particular island group they were ated by areas of the ocean 10 degrees of latitude high and 10 degrees of longi- wide (table 3). The bird sightings were tabulated by number only, because the rence of flocked birds is a rarity at these distances from emergent land.

It has already been inferred that there are fewer birds in the open ocean than e island and semioceanic areas. This is very pointedly shown in table 3, for ean number of birds sighted per day for all oceanic observations is only 37.2, as 135.6 were seen per day in the semioceanic areas (table 2). Fish schools sighted at the rate of only 0.5 per day in the oceanic area as against 2.3 per n the semioceanic areas. Thus it appears that the reduction in the fish ls sighted is almost exactly proportional to the reduction in numbers of birds. coupled with the acknowledged difficulty of locating schools of fish unless are accompanied by birds, leads us to question whether the actual abundance sh is any less in the open ocean than it is nearer to land.

Table 2.--Summary of semioceanic[1] observations associated with particular island groups

Locality	Period	Number of days		Yellowfin		Skipjack		Unidentified		Total fish schools		Bird flocks		Number of birds[3]	
		Fishing and scouting	Running	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day
Line Is.	Mar.-May	0	1	0	0.0	1	1.0	0	0.0	1	1.0	1	1.0	30	30.0
	June-Aug.	0	2	0	0.0	0	0.0	0	0.0	0	0.0	1	0.5	37	18.5
	Sept.-Nov.	0	3	1	0.3	2	0.7	6[2]	2.0	9	3.0	12	4.0	162	54.0
	Dec.-Feb.	0	17	0	0.0	10	0.6	21	1.2	31	1.8	36	2.1	959	56.4
Total and average[4]		0	23	1	0.1	13	0.6	27	0.8	41	1.4	50	1.9	1188	39.7
Phoenix Is.	Mar.-May	0	4	0	0.0	1	0.2	4	1.0	5	1.2	8	2.0	310	77.5
	June-Aug.	0	2	2	1.0	3	1.5	1	0.5	6	3.0	13	6.5	615	307.5
	Sept.-Nov.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dec.-Feb.	0	4	0	0.0	0	0.0	0	0.0	0	0.0	1	0.2	43	10.8
Total and average[4]		0	10	2	0.3	4	0.6	5	0.5	11	1.4	22	2.9	968	131.9
Hawaiian Is.	Mar.-May	0	10	0	0.0	3	0.3	5	0.5	8	0.8	12	1.2	558	55.8
	June-Aug.	1	8	0	0.0	4	0.4	10	1.1	14	1.6	19	2.1	1212	134.7
	Sept.-Nov.	0	16	0	0.0	10	0.6	7	0.4	17	1.1	16	1.0	1283	80.2
	Dec.-Feb.	0	7	0	0.0	1	0.1	1	0.1	2	0.3	3	0.4	144	20.6
Total and average[4]		1	41	0	0.0	18	0.4	23	0.5	41	1.0	50	1.2	3197	72.8
Leeward Is.	Mar.-May	0	2	0	0.0	2	1.0	1	0.5	3	1.5	3	1.5	85	42.5
Jarvis I.	Sept.-Nov.	0	1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	35	35.0
	Dec.-Feb.	0	2	0	0.0	2	1.0	0	0.0	2	1.0	8	4.0	352	176.0
Malden I.	June-Aug.	0	1	0	0.0	1	1.0	0	0.0	1	1.0	3	3.0	94	94.0
Starbuck I.	Sept-Nov.	0	1	0	0.0	0	0.0	2	2.0	2	2.0	2	2.0	86	86.0
	Dec.-Feb.	0	5	0	0.0	2	0.4	17	3.4	19	3.8	22	4.4	1172	234.4
Johnston I.	Mar.-May	0	1	0	0.0	1	1.0	0	0.0	1	1.0	2	2.0	11	11.0
Marquesas Is.	Mar.-May	0	1	0	0.0	0	0.0	0	0.0	0	0.0	1	1.0	16	16.0
	June-Aug.	0	4	0	0.0	1	0.2	3	0.8	4	1.0	5	1.2	309	77.2
Samoa - Nukunono Is.	Dec.-Feb.	0	3	0	0.0	0	0.0	2	0.7	2	0.7	2	0.7	12	4.0

1/ Semi-oceanic observations were considered to be from 60 to 180 miles from the islands.
2/ 2 schools of little tunny.
3/ Includes scattered birds.
4/ Unweighted averages.

Table 3.--Summary of oceanic observations of fish schools and birds. The sightings are summarized by rectangles bounded by 10° of latitude and 10° of longitude and identified by coordinates of the southeast corner

Location	Number of days	Number of birds	Fish schools			
			Yellowfin	Skipjack	Unidentified	Total
20°N - 110°W	2	6	-	-	-	-
20°N - 150°W	5	17	-	-	-	-
20°N - 160°W	1	7	-	-	-	-
20°N - 170°W	1	-	-	-	-	-
10°N - 110°W	2	147	-	-	2	2
10°N - 120°W	1	234	-	-	3	3
10°N - 130°W	5	321	1	-	2	3
10°N - 140°W	16	970	-	1	8	9
10°N - 150°W	32	1,395	-	7	12	19
10°N - 160°W	29	171	-	1	-	1
Q - 120°W	2	34	-	-	-	-
Q - 130°W	12	286	1	1	2	4
Q - 140°W	18	800	1	5	5	11
Q - 150°W	9	780	1	3	8	12
Q - 160°W	22	645	-	-	8	8
Q - 170°W	11	100	-	-	1	1
Q - 180°	1	3	-	-	-	-
10°S - 120°W	4	316	-	3	6	9
10°S - 130°W	4	46	-	-	-	-
10°S - 140°W	9	187	-	-	1	1
10°S - 150°W	2	12	-	1	-	1
10°S - 160°W	9	975	1	8	8	17
10°S - 170°W	8	182	-	-	4	4
Total	205	7,634	5	30	70	105

As in the semioceanic areas, the dominant fish species in the oceanic area is kipjack. This lends further weight to the conclusion that surface schools of yellowfin are principally associated with land in the central Pacific, alh they have been observed far from land.

There is some indication of seasonality in the frequency of sightings of nic fish schools and birds. As shown in figure 5, there were more schools ted from June to November than during the rest of the year. This seasonal pat- is similar to that of the Line and Phoenix islands (fig. 5), but is divergent the Hawaiian Islands (the island group for which we have the most sightings), nown in figure 6.

The differences between the Hawaiian and oceanic sightings may be the result ne nesting cycles of the birds. The peak in Hawaiian sightings (March-August) rs during what is presumably the peak in the nesting cycles of the birds hardson and Fisher 1950), when their daily flying range tends to be restricted he vicinity of the nesting sites. On the other hand, the peak in the oceanic e appears to occur at the season when nesting is reduced (September-November) the birds are free to fly greater distances from land.

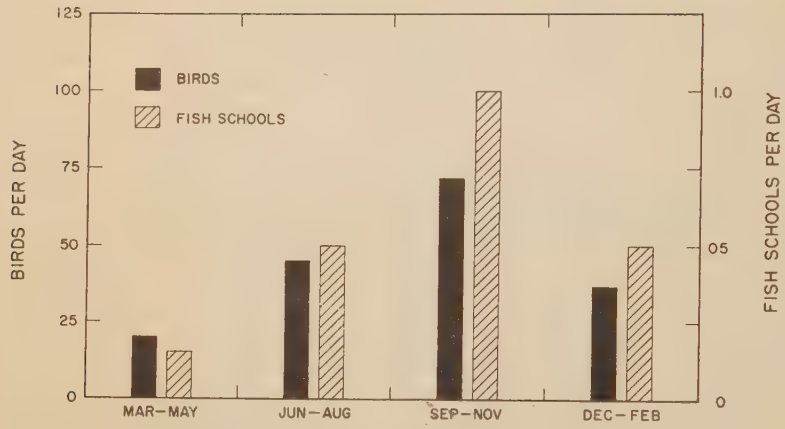


Figure 5.--Seasonal distribution of oceanic fish school and bird sightings.

It is evident from sighting records in tabl that there was great var tion in the numbers of b and fish schools seen in ferent parts of the ocea zone. It is impossible examine this variation t determine longitudinal t but sampling in the cent portion of the area (140° 170°W. longitude) is aded to permit study of latitu nal variation. Considere interest is attached to l tudinal variation because sightings were made over three current systems of equatorial Pacific: the North Equatorial Current, lying roughly north of 10° latitude, the Countercurr between 5° and 10°N. lati and the South Equatorial Current south of the Countercurrent.

The rate of sighting birds and fish schools varied considerably among the different current systems (fig. 7) and within current systems. In the North Equatorial Current, north of 20°N., abundance is very low, though of course the sample is inadequate. Between 10° and 20°N. abundance is greater, though still a rather low order of magnitude. In the Countercurrent abundance is high, an ob servation first made by Brooks (1934), who noted that birds were more abundant i that region than to the north or south during a crossing from San Francisco to Tahiti near 140°W. longitude. Birds and fish schools are relatively scarce in t South Equatorial Current between the Equator and 5°N. latitude. South of the Equator our observations suggest a large population of birds and fish (fig. 7), examination of the field records shows that nearly all of the schools of fish we sighted during one week of February 1952, and very few sightings were made durin the balance of the year (the observations were distributed through seven months) This is not typical of the information from the other areas, for the field recor show that the fish schools and birds noted were well distributed in time and sp Thus we are inclined to th view that the high rate of sighting south of the Equa (fig. 7) is in part a sam- pling accident, and that t information is not strictl comparable with that obtai north of the Equator.

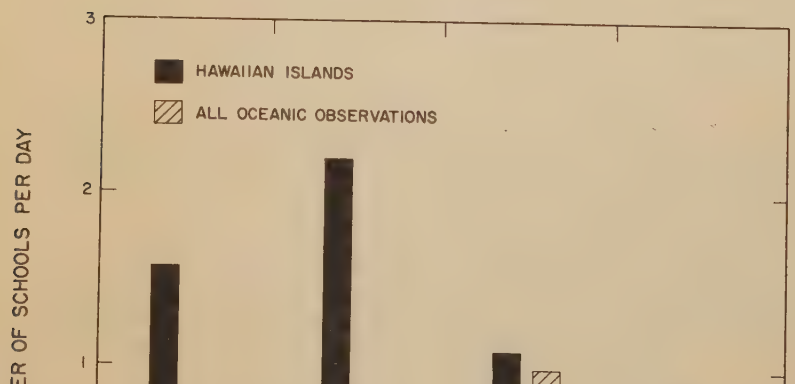
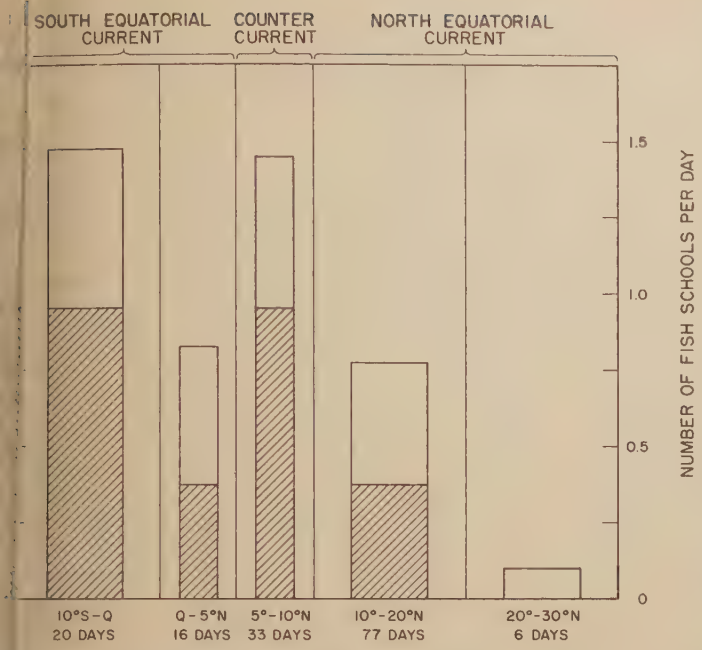


Figure 6.--Comparison of number of schools sighted per day in Hawaiian waters and oceanic waters.

The distribution of surface schools and birds (fig. 7) is different from the distribution of sub- surface or deep-swimming fishes, particularly the yellowfin tuna, as noted b Murphy and Shomura (1953a, These papers report the re- sults of systematic longli fishing across the equator current systems. The yell fin catches summarized in figure 8 show that, on the average, abundance is zero the North Equatorial Curre



e 7.--Oceanic sightings between 140°W. gitude and 170°W. longitude summarized by itude. The height of the bar represents the rage bird count per day, and the shaded por- n the average number of fish schools per day, ther or not they were accompanied by birds. e number of days' observations is shown below h bar. The zone between the Equator and 10° has been considered in two portions because e Countercurrent lies between 5° and 10°N. th of the Countercurrent is the North Equa- rial Current and south of it flows the South uatorial Current.

moderate in the Countercurrent, greatest in the South Equatorial Current between the Equator and 5°N., where surface fish schools were scarce, and relatively low south of the Equator.

The difference between surface sightings and longline catches may be related to the difference in the species of fish involved, for the longline takes mostly yellowfin and to a lesser extent bigeye tuna and the surface sightings are predominantly skipjack. These species undoubtedly have different ecological requirements, and so there is little reason to expect their distributions to be coincidental.

TROLLING

Trolling represents a method of directly sampling the surface populations of fishes. It is a direct measure inasmuch as the location of fish is not so dependent on some associated phenomenon such as flocks of birds. For this reason it potentially provides an independent check on the relative abundance of fish as determined by sightings. There were two types of trolling carried out on POFI vessels, secondary and primary trolling.

econdary trolling is conducted as a routine activity whenever vessels are way during daylight hours unless it would interfere with more important ns. The speed of the vessel is not adjusted to facilitate trolling, and no t is made to fish in favorable locations or to work the schools of fish en- red. The usual cruising speed of the POFI vessels (7 to 10 knots) does not de hooking fish, but there have been occasions when hooked fish were lost be- of the difficulty of handling them from a rapidly moving vessel. After y 1952 the method of surface trolling was standardized. Two 25-fathom lines ished, one from each side of the stern. One line was equipped with a 6-ounce ad jig with white and Plymouth Rock feathers and a 9/0 double hook. The line had a red bone jig with a 9/0 double hook. Before that time two lines ying lengths and a variety of lures had been used, but we doubt that these ions had a significant effect on the catch.

n a number of occasions the primary type of trolling has been done, particu- in the vicinity of islands. In contrast to secondary trolling, the ship's is brought down to about 6 knots and attempts are made to work favorable and the schools of fish encountered. Usually 4 to 6 lines were fished from ern of the vessel, and various lures were used. These lures were of the same l type and size as those used in secondary trolling. (For details of primary ng see Bates 1950.)

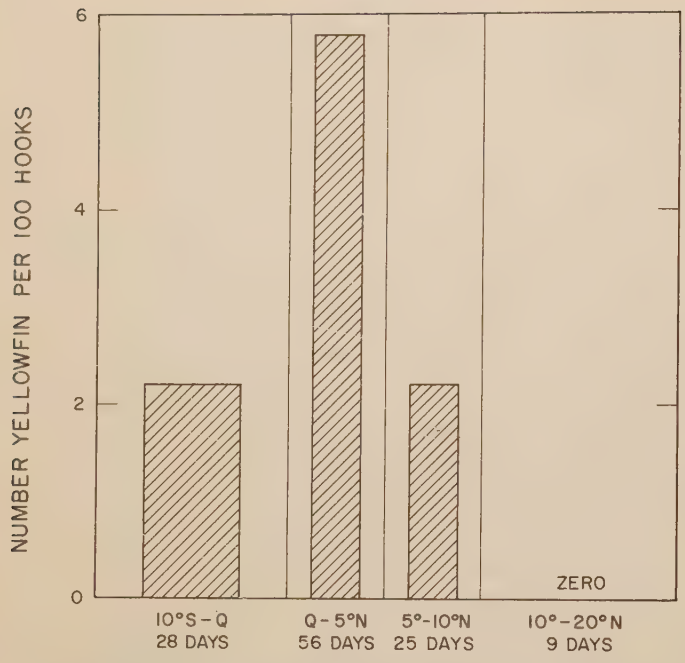


Figure 8.--Results of longlining between 140°W. and 170°W. longitude during 1950-52.

The results of the 8,937 hours of secondary and primary trolling have been organized g graphically in the same manner the surface sightings, the two types of trolling being treate separately. These data will b examined for information on the distribution of tuna and will b compared with the surface sight for consistency between the two measures of abundance. The sea sonal distribution of the troll catches will not be analyzed be cause of the paucity of data.

It should be noted particu larly that trolling, both secon and primary, fails to sample sk jack as efficiently as it sampl yellowfin. It is commonplace t troll through visible concentra tions of skipjack without strik whereas yellowfin are nearly al taken when there are indication of their presence. In the Hawai area Welsh (1950) reported captu of approximately one yellowfin i each two skipjack by trolling, a ratio in close agreement with PO secondary trolling in the Hawaii area. But contrasted with this, commercial landings by the Hawai livebait fishery are less than 1 yellowfin for 100 skipjack, showing that trolli takes a far smaller proportion of skipjack than livebait fishing does. Parallel these observations, the results of surface sightings discussed in earlier sectio indicate, for all areas, a greater relative abundance of skipjack than was shown the troll catches, leading to the conclusion that skipjack are relatively more abundant in most areas than is indicated by trolling.

Island Trolling

One of the earliest published reports on island tuna trolling in the central Pacific (Chapman 1946) indicated an abundance of skipjack and yellowfin in the vicinity of the Line and Phoenix islands. Welsh (1950) has published the result of a general trolling survey of the Hawaiian Islands, indicating that skipjack a little tunny predominated in that area. Bates (1950), reporting on a portion of the POFI trolling in the Line Islands, suggested that the island populations of yellowfin there were abundant enough for commercial trolling.

There has been no primary trolling by POFI in Hawaiian waters, but data of Welsh (1950) are available for comparison with the various island areas. He reported on 307 hours of trolling with 7 lines, the total catch amounting to 548 fish: 46 skipjack, 23 yellowfin, 350 little tunny, 101 dolphin, 8 jacks, and 20 wahoo. The survey was made during the period March 1948 to June 1949, and most the trolling was done around Oahu. In terms of catch per 100 line-hours, the average for all tunas was approximately 19.5. By species it was 1.1 yellowfin, skipjack, and 16.3 little tunny. These catches are lower than those reported by Tester (1952) (about 27 tuna per 100 line-hours), but his fishing was all done in particularly productive area off Kaneohe Bay, Oahu.

Primary trolling by POFI vessels in the Line Islands (table 4) indicated a much higher catch rate than in the Hawaiian Islands, and the catches were domina by yellowfin. There were 890 line-hours of trolling with a catch of 241 yellowf 5 skipjack, 171 wahoo, 11 jacks, 8 rainbow runners, and 24 miscellaneous fish. average for tuna was 27.6 per 100 line-hours, practically all yellowfin. The si of the yellowfin ranged from 13 to 69 pounds. It is probable that larger yellow

Table 4.--Results of trolling in island areas

Species	Number caught, by locality											
	Line Islands	Phoenix Islands	Hawaiian Islands	Leeward Hawaiian Islands	Malden Island	Starbuck Island	Jarvis Island	Samoa Islands	Marquesas Islands	Nukunono Island	Johnston Island	Total
[illegible] trolling:												
[illegible]owfin	241	34	-	1	7	11	29	-	-	-	-	323
[illegible]jack	5	0	-	0	0	0	0	-	-	-	-	5
[illegible]le tunny	0	0	-	0	0	0	0	-	-	-	-	-
[illegible]tal	246	34	-	1	7	11	29	-	-	-	-	328
[illegible]LANEOUS												
[illegible]hin	0	0	-	0	0	0	0	-	-	-	-	-
[illegible]o	171	7	-	0	3	8	12	-	-	-	-	201
[illegible]s	11	0	-	0	1	0	0	-	-	-	-	12
[illegible]bow runner	8	0	-	0	0	0	0	-	-	-	-	8
[illegible]rs	24	0	-	0	1	0	0	-	-	-	-	25
[illegible]tal	214	7	-	0	5	8	12	-	-	-	-	246
[illegible]and Total	460	41	-	1	12	19	41	-	-	-	-	574
[illegible] hours	890	79	-	13	14	20	12	-	-	-	-	1,028
[illegible]./100 line [illegible]s	27.6	43.0	-	7.7	50.0	55.0	241.7	-	-	-	-	31.9
[illegible] species/100 [illegible] hours	51.5	51.8	-	7.7	85.6	95.0	341.7	-	-	-	-	55.8
[illegible]lary trolling:												
[illegible]lowfin	34	1	3	0	0	0	0	0	0	0	3	41
[illegible]pjack	1	0	6	0	0	0	0	0	0	0	0	7
[illegible]tle tunny	0	0	1	7	0	0	0	0	0	0	0	8
[illegible]otal	35	1	10	7	0	0	0	0	0	0	3	56
[illegible]LLANEOUS												
[illegible]phin	0	0	11	2	0	0	0	1	0	0	0	14
[illegible]oo	17	3	2	1	0	0	0	0	0	0	0	23
[illegible]ks	1	0	0	0	0	0	0	0	0	0	0	1
[illegible]nbow runner	2	0	0	0	0	0	0	0	0	0	0	2
[illegible]ers	2	0	0	0	0	0	0	0	0	0	0	2
[illegible]otal	22	3	13	3	0	0	0	1	0	0	0	42
[illegible]rand total	57	4	23	10	0	0	0	1	0	0	3	98
[illegible]e hours	739	339	930	173	8	10	46	29	22	32	56	2,384
[illegible]a/100 line [illegible]rs	4.7	0.3	1.1	4.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	2.3
[illegible] species/100 [illegible]e hours	7.7	1.2	2.5	5.8	0.0	0.0	0.0	3.4	0.0	0.0	5.4	4.1

were not as well represented in the catches as they were in the population sin largest fish hooked were most frequently lost.

Trolling surveys in the Phoenix Islands indicate an even higher catch rat in the Line Islands (table 4), but the sample is somewhat smaller and may not b reliable. The Phoenix Island catches closely resembled in species composition from the Line Islands, with a catch of 43.0 tuna per 100 line-hours, all of the yellowfin.

The amount of primary trolling at other island areas in the central Pacifi (table 4) was inadequate for an evaluation of abundance, but very good catch ra for yellowfin were experienced during the few hours of trolling performed at Ma Starbuck, and Jarvis islands.

The secondary trolling (table 5) is less reliable than the primary trolling an index of relative abundance among the several island groups because tuna trol in all the island areas, possibly excluding the Hawaiian Islands, is particularl productive in very specialized locations, usually near reefs. Inasmuch as these cations were only occasionally and unsystematically traversed during secondary t ling the catches do not afford unbiased estimates for the several island areas. records will, however, be useful later in the discussion.

Oceanic and Semioceanic Trolling

The 5,525 line-hours of secondary oceanic and semioceanic trolling resulted a very low tuna catch. Only 70 fish were landed: 7 skipjack, 8 yellowfin, 40 dolphin, 12 wahoo, 1 little tunny, 1 black marlin, and 1 barracuda (table 5). T is an average of 1.3 fish per 100 line-hours, 0.3 of which were tuna.

Table 5.--Results of semioceanic and oceanic trolling

	Semioceanic	Oceanic
Line-hours	1,834	3,691
Skipjack	3	4
Yellowfin	3	5
Little tunny	-	1
Wahoo	3	9
Black marlin	-	1
Barracuda	-	1
Dolphin	20	20
Total catch	29	41
Catch/100 line-hours	1.6	1.1

It is of particular interest to note that the nearly equal catches in the oceanic and semioceanic trolling (table 5) are at variance with the number of sur face schools, which were seen 5 times as frequently in the semioceanic zone (page 7). Thus it appears likely that the greater relative number of sightings in the semioceanic areas is mainly a reflection of the greater abundance of birds within 180 miles of islands. This confirms the surmise in the previous section that the fish school sightings decreased when passing from the semioceanic to the oceanic provinces because the bird population decreased.

The secondary trolling in the semioceanic zone resulted in smaller tuna catc (0.3 per 100 line-hours) than the secondary trolling in the combined island zones (2.3 per 100 line-hours) (tables 4 and 5), suggesting differences in abundance th were not evident from the sightings. Actually, the higher troll catch in the

zones probably does not represent a difference in general tuna abundance but main reflects the higher relative populations near land of easily captured fin. In addition, the reef areas, known to harbor concentrations of yellow- re occasionally traversed during secondary trolling, erratically increasing sults of insular secondary trolling.

DISCUSSION

he sightings and trolling catches suggest several generalizations on the bution of surface tunas in the central Pacific. First, close to the reefs appear to be concentrations of tunas dominated by the yellowfin. Beyond the ate vicinity of the reefs the presence of land does not seem to affect the nce of tuna but does affect the species composition. Yellowfin schools are d more frequently in the island than in the semioceanic and oceanic zones, skipjack dominate. This may indicate that the presence of land alters the y in such a way that yellowfin can exist in larger numbers in the adjacent . Skipjack, on the other hand, dominate the semioceanic and oceanic zones, almost completely replaced by yellowfin in the island zones of the Line and x islands, and to a limited degree of the Hawaiian Islands.

Since it appears that the mere presence of land does not alter the density of una population, except in limited areas, we should consider the possibility the different levels of abundance (disregarding species) in different island ceanic areas are a function of different levels of general productivity of ic waters. To examine this hypothesis, it is necessary to suppress variation e tuna population associated with different seasons, either by comparing dif- t areas in the same season or by making comparisons between areas having sentation throughout the year. The latter course appears the sounder, because not have the information on homologous seasons, and if comparisons are limited gments of the year there is danger of comparing one area at its peak with er area at an "off season." Finally, comparisons must be restricted to areas nes equally accessible to aquatic birds, because most schools are overlooked s working birds advertise their presence.

In order to compare the relative abundance of fish schools with productivity all use the standing crop of zooplankton, the level of which has been shown to lated to the oceanic circulation (Cromwell 1954, King and Demond 1953, Sette tc.), as an index of relative oceanic productivity. Considering the three d areas, King and Demond (1953) provide data indicating that the relative order land groups with respect to zooplankton abundance is Hawaiian Islands, Phoenix nds and Line Islands in ascending order. If these same groups of islands are d according to the apparent abundance of fish schools, using the average of nweighted average quarterly sighting rates from table 1 (1.4, 1.9, 2.1), their remains unchanged. A similar comparison of fish-school abundance using the ceanic sightings (table 2) gives the same order, though the comparison is less lse because of poor stratification in time.

In the oceanic area the abundance of surface fish and birds does not conform to abundance of plankton as well as in the insular areas. King (MS) indicates north of 10°N. the abundance of zooplankton is relatively low as is also the dance of birds and fish schools. In the Countercurrent he reports considerably zooplankton than to the north, and here surface schools are also relatively dant. In the South Equatorial Current between the Equator and 5°N. latitude he rts even more zooplankton than in the Countercurrent, but fish schools are only t as abundant as in the zooplankton-poor region north of the Countercurrent. h of the Equator (0° to 10°S.) there is somewhat less zooplankton than in the tercurrent, but fish schools are slightly more abundant than in any of the zones r consideration, though there is reason to suspect that the sampling south of Equator has not been adequate.

The discrepancies between fish schools and plankton in the oceanic area may be in serious conflict with the general idea that the size of the population of mals (fish and birds) at one trophic level is related to the size of the popula- n at lower levels (plankton), for we are here considering only one element of fish population (surface schools that are mostly skipjack). It was pointed out t the distribution of surface schools does not correspond with the distribution subsurface or deep-swimming tunas (mostly yellowfin). The fact that deep- mming yellowfin tuna are most abundant in regions of few surface tuna schools

(0 to 5°N. lat.) suggests that if it were possible to consider quantitatively th higher vertebrate fauna as a whole, there might be better agreement in the hori- zontal distribution of the groups of organisms at different trophic levels.

However, the question still remains: Why does the zone with low numbers of surface skipjack schools coincide with the zone of high numbers of deep-swimming yellowfin tuna? Sampling is, of course, always suspect, particularly in this in stance, when the critical region (0° to 5°) is represented by only 16 days, thou these were well distributed in time and space. The possibility of competition w other species was inferred above. An alternative hypothesis is that the vertica distribution of food organisms in the region of low surface sightings differs in such a way that the fish do not spend as large a fraction of their life at the s face as they do in the adjacent areas to the north. Or, even if differences in t vertical distribution of food organisms do not affect fish, the differences might affect the density of aquatic birds, thus altering the apparent abundance of surf schools of fish.

SUMMARY

1. During the period October 17, 1950, to April 4, 1953, there were 546 days dur which surface trolling and bird and fish watches were maintained on POFI vess in the central Pacific. These observations have been separated into "island" (0 to 60 miles from land), "semioceanic" (60 to 180 miles from land), and "oceanic" (more than 180 miles from land) provinces.

2. The seasonal pattern of frequency of daily sightings in the Hawaiian Islands area closely resembles the seasonal pattern of landings of the commercial tun fishery. The frequency of fish sightings appears to be a function of the abun dance of birds.

3. The seasonal patterns in the Hawaiian, Line, and Phoenix islands are similar, with greater frequency of sightings during the period June to November.

4. Skipjack dominate the surface schools in the Hawaiian area, and yellowfin dominate in the Line and Phoenix islands.

5. The frequency of sightings in semioceanic areas is approximately the same as i the island areas.

6. The frequency of sightings in the oceanic areas in general was lower than in island and semioceanic areas.

7. Skipjack are evidently the dominant surface tuna in the oceanic and semioceani areas, and surface yellowfin, if not dominant, at least are relatively more abundant close to land.

8. There is an indication of seasonality in the abundance of surface schools in the oceanic area, probably differing from the seasonal pattern in island and semioceanic areas.

9. Trolling indicated a relatively high abundance of tunas, particularly yellowfi in the near proximity of islands, with a uniformly low abundance in the semi- oceanic and oceanic areas.

10. The evidence indicates that the abundance of surface schools near islands in the central Pacific is a function of the standing crop of plankton. In the oceanic area the abundance of surface schools and birds does not closely paral lel the abundance of plankton.

Table 6.--List of cruises during which the data used in this report were gathered

Vessel	Cruise number	Cruise period	Primary mission	Captain of vessel	Field party chief
Hugh M. Smith	7	Oct. 17 to Nov. 30, 1950	Longline fishing	O. J. Heggem	F. C. Cleaver
"	8	Jan. 14 to Mar. 14, 1951	Hydrographic	O. J. Heggem	J. E. King
"	9	May 5 to July 2, 1951	Livebait fishing	A. K. Akana	F. C. June
"	10	July 19 to July 31, 1951	Hydrographic	R. L. Johnson	J. E. King
"	11	Aug. 20 to Oct. 6, 1951	Longline - hydrographic	R. L. Johnson	T. Cromwell
"	12	Oct. 23 to Nov. 3, 1951	Hydrographic	R. L. Johnson	H. J. Mann
"	14	Jan. 23 to Mar. 13, 1952	Hydrographic	R. L. Johnson	G. I. Murphy
"	15	May 21 to July 1, 1952	Hydrographic	G. L. Wilkinson	J. E. King
"	16	July 23 to Aug. 29, 1952	Hydrographic	R. L. Johnson	T. Cromwell
"	17	Sept. 5 to Sept. 15, 1952	Hydrographic	R. L. Johnson	J. E. King
"	18	Oct. 7 to Nov. 22, 1952	Longline - hydrographic	R. L. Johnson	G. I. Murphy
"	19	Jan. 8 to Feb. 12, 1953	Longline - hydrographic	R. L. Johnson	J. E. King
"	20	Feb. 25 to April 4, 1953	Hydrographic	R. L. Johnson	T. Cromwell
John R. Manning	4	Oct. 26 to Dec. 6, 1950	Purse seining	H. Olsen	T. J. Roseberry
"	5	Jan. 11 to Mar. 2, 1951	Purse seining	H. Olsen	J. E. Rawlings
"	6	Mar. 30 to May 17, 1951	Purse seining	H. Olsen	T. J. Roseberry
"	7a	June 5 to June 18, 1951	Purse seining	H. Olsen	E. L. Niska
"	7b	July 21 to Aug. 15, 1951	Purse seining	J. Vilicich	G. I. Murphy
"	7c	Aug. 21 to Sept. 8, 1951	Purse seining	J. Vilicich	G. I. Murphy
"	8	Sept. 23 to Oct. 19, 1951	Gillnet fishing	G. L. Wilkinson	W. M. Matsumoto
"	9a	Nov. 13 to Nov. 19, 1951	Plankton sampling	G. L. Wilkinson	J. E. King
"	9b	Nov. 26 to Nov. 27, 1951	Plankton sampling	G. L. Wilkinson	J. E. King
"	11	Jan. 24 to Mar. 19, 1952	Longline fishing	G. L. Wilkinson	G. I. Murphy
"	12	Aug. 6 to Sept. 15, 1952	Longline fishing	G. L. Wilkinson	W. F. Royce
"	13	Oct. 16 to Dec. 6, 1952	Longline fishing	G. L. Wilkinson	T. Otsu
"	14	Jan. 22 to Mar. 25, 1953	Longline fishing	G. L. Wilkinson	W. G. Van Campen
Charles H. Gilbert	1	May 20 to June 21, 1952	Longline fishing	R. L. Johnson	W. G. Van Campen
Cavalieri	1a	June 11 to July 1, 1952	Longline fishing	R. E. K. D. Lee	D. L. McKernan
"	1b	Aug. 13 to Sept. 27, 1952	Longline fishing	R. E. K. D. Lee	D. L. McKernan

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LONGLINE FISHING FOR DEEP-SWIMMING TUNAS IN THE CENTRAL PACIFIC, AUGUST-NOVEMBER 1952

SPECIAL SCIENTIFIC REPORT–FISHERIES No. 137

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Explanatory Note

The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

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United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

LONGLINE FISHING FOR DEEP-SWIMMING TUNAS IN THE CENTRAL PACIFIC, AUGUST-NOVEMBER 1952

By

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The Pacific Oceanic Fishery Investigations (POFI) is conducting a survey of the fishery resources of the central Pacific. Early in its program it became apparent that the various species of tuna in this area represented a potential source of raw material for the American canning industry. Further study showed that the deep-swimming tunas, particularly the yellowfin, which may be caught by longline, were the most immediately available, and furthermore, the resource appeared to be large enough to support a substantial fishery. Studies were then initiated to determine the magnitude of the resource, its geographical distribution throughout the year, and the environmental factors that control distribution and abundance. Included in this program was a series of longlining cruises which were to cross the equatorial region between 120° W. and 180° longitude.

Two previous reports (Murphy and Shomura 1953a, b) cover the results of longline fishing from July 1950 to June 1952. The present report includes the results of four cruises to equatorial waters during the period August to November 1952. The catches are examined in relation to the environment, and a summary is given of the geographical and vertical variation in the catch rates. In connection with geographical variation a summary is given of selected Japanese commercial fishing catches. There is included a résumé of the size distribution of longline-caught yellowfin and bigeye tuna across the equatorial Pacific, and an analysis of the sex ratios of the yellowfin tuna. Finally, certain topics of particular interest to commercial fishermen, such as gear design and shark damage are briefly discussed. The summarized field data from the four cruises appear in the appendix.

We use the common names of the fishes throughout this report. These, with their commonly accepted scientific names, are as follows:

White-tipped shark, Carcharinus longimanus (Poey)
Silky shark, Carcharinus sp. 1/
Great blue shark, Prionace glauca (Linnaeus)
Bonito shark, Isurus glaucus (Müller and Henle)
Marlin, Makaira sp.
Sailfish, Istiophorus orientalis (Schlegel)
Wahoo, Acanthocybium solandri (Cuvier and Valenciennes)
Dolphin, Coryphaena hippurus (Linnaeus)
Yellowfin tuna, Neothunnus macropterus (Temminck and Schlegel)
Bigeye tuna, Parathunnus sibi (Temminck and Schlegel)
Skipjack, Katsuwonus pelamis (Linnaeus)
Albacore, Germo alalunga (Bonnaterre)
Lancet fish, Alepisaurus sp.
Barracuda, Sphyraena barracuda (Walbaum)

Several persons were responsible for the execution of the fishing cruises. Included among the field parties were T. S. Hida, I. I. Ikehara, W. M. Matsumoto, D. L. McKernan, T. Otsu, T. J. Roseberry, and W. F. Royce. Considerable assistance in the planning of the cruises was rendered by O. E. Sette. The successful completion of the fishing was due in no small part to the cheerful cooperation of the officers and fishermen of the three vessels. T. S. Austin and the writers prepared the temperature profiles. Wilvan Van Campen translated the Japanese commercial catch data, and Jean Halling assisted in processing the catch records.

MATERIAL AND METHODS

The four cruises included in this report are (1) John R. Manning cruise 12, with lines of fishing stations across the Equator on 140° W. and 150° W. longitude; (2) Cavalieri cruise 1, a semicommercial fishing trip (McKernan 1953), with a line of stations fished south from 9° N. on 140° W. to the Equator followed by a series of stations north of the Equator between 140° W. and

1/ A species closely resembling C. floridanus Bigelow, Schroeder, and Springer, and C. ahenea (Stead).

150°W. longitude; (3) Hugh M. Smith cruise 18, with lines of fishing stations across the Equator along 120°W. and 130°W. longitude; and (4) John R. Manning cruise 13, with fishing sections across the Equator on 150°W. and 169°W. longitude.

The Cavalieri cruise warrants special mention because it represented an attempt at commercially harvesting the equatorial longline tuna resource. During this cruise considerably more gear was fished than during experimental surveys by POFI vessels. The design of the gear was identical to that used by POFI, and the daily fishing schedule was comparable except that more time was spent setting and hauling the greater number of baskets fished.

The gear used on the four cruises covered by this report was similar in construction to that used during previous POFI exploratory fishing, except that small amounts of specially designed gear were fished during some trips. Complete descriptions of the "standard" gear that formed the bulk of each set are furnished by Niska (1953) and Murphy and Shomura (1953a).

Briefly, each basket of the standard longline gear consisted of a main line 1,260 feet long suspended by 60-foot buoy lines and bearing six-hook droppers attached at 180-foot intervals. These droppers made of cotton line and steel leaders were about 88 feet in overall length. At each station the gear was set at dawn, and hauling commenced about noon. Setting took from 1 to 1.5 minutes per basket and hauling about 5 minutes per basket (tables 20-23). Thus, the operational aspect of these cruises was identical with past surveys except that different baits were used.

On earlier cruises the bait had been almost exclusively sardine. During these cruises other baits, such as herring and squid, and various methods for attaching the bait to the hook were tested. The results of these experiments are not reported herein except to note that the experimental baits and baiting methods did not appreciably alter the catch rates (Shomura MS), enabling us to disregard this factor in our evaluation of the abundance of tunas.

GEOGRAPHICAL VARIATION IN THE CATCH RATES

The four cruises during the period August-November 1952 (fig. 1) provide estimates of the abundance of deep-swimming tunas in the equatorial region over a wide range of longitudes (120°W. to 170°W.). Previous fishing during this general season in 1950 and 1951 indicated a concentration of yellowfin tuna between 1°N. and 6°N. latitude at 150°W. to 160°W. longitude (Murphy and Shomura 1953a). The results of the 1952 surveys provide a check on these earlier findings and also extend the geographical coverage during the period August to November.

By way of review of previous results and the general concepts utilized in their interpretation, it should first be pointed out that the prevailing winds in the mid-Pacific equatorial region during the period August to November are from the southeast quadrant (U. S. Pilot Charts). According to Cromwell (1953), these winds create divergence and upwelling at the Equator and tend to displace the upwelled water northward. This nutrient-rich upwelled water supports a larger population of zooplankton than the waters to the north and south (King and Demond 1953), and it was expected that this increase in the basic animal food would be reflected in the abundance of the larger fishes. Several fishing sections across the Equator indicated that the tuna, in particular the yellowfin, were indeed more abundant in the zone of enrichment (Murphy and Shomura 1953a, b).

The results of these four latest cruises will be considered in the light of previous findings, with attention focused on the yellowfin tuna catches, and the environmental circumstances associated with these catches followed by a brief discussion of the apparent distribution of albacore along the Equator. The catches of the other tunas are not singled out for special attention, but are included in tabular form in order to indicate the relative levels of abundance of the several species in the catch.

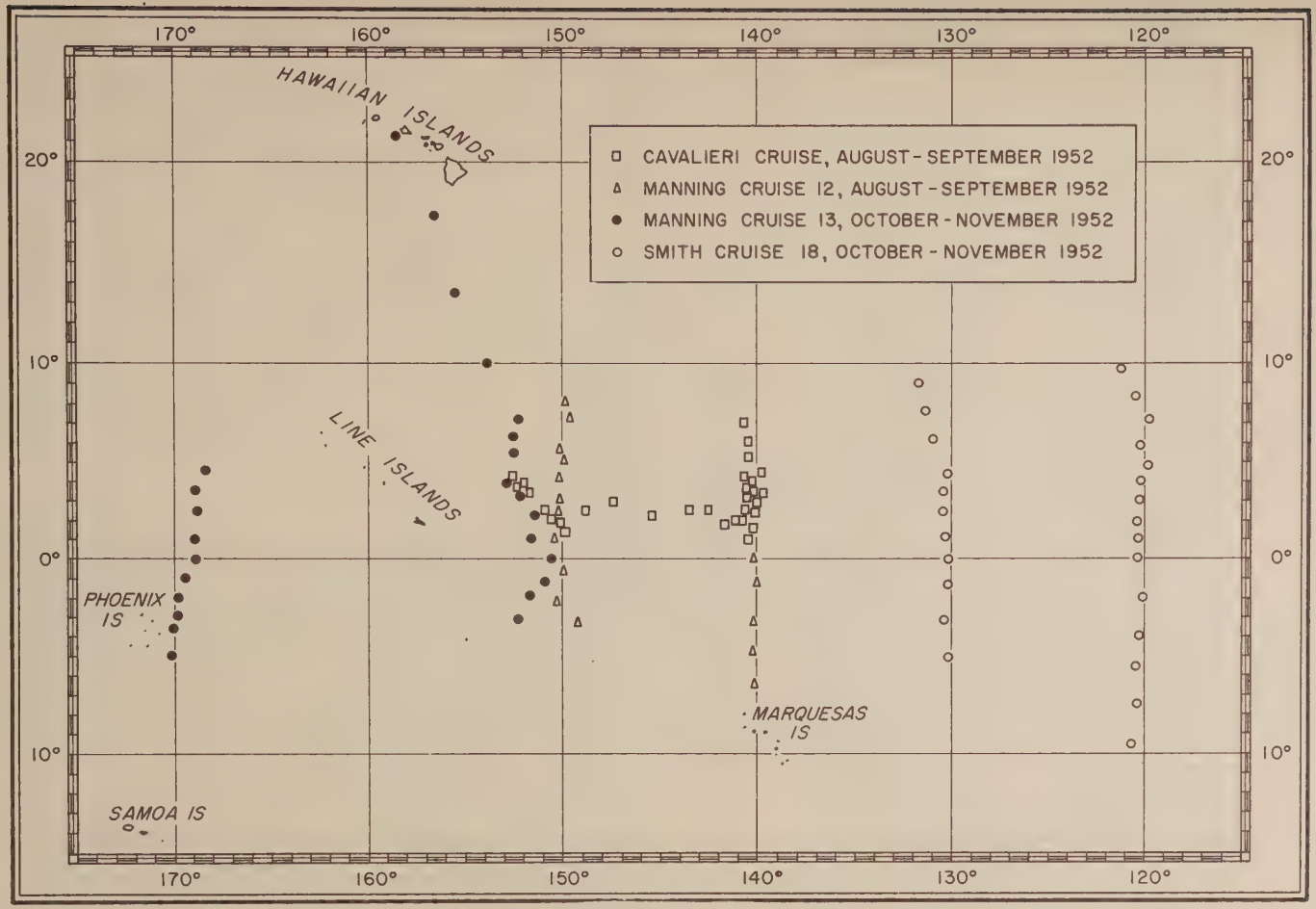

Figure 1.--Locations of fishing stations, Cavalieri cruise 1, Manning cruises 12 and 13, and Smith cruise 18.

Yellowfin Tuna

The yellowfin catches of these four cruises indicate a center of abundance in the region of 140°-150°W. longitude, just north of the Equator. East and west of this zone the abundance fell off markedly, particularly to the east. This agrees in general with earlier findings.

The section at 120°W. longitude (fig. 2, table 1) gives evidence of very intense upwelling of the type described by Cromwell (1953). This is indicated by the cooler surface water at the Equator. The general distribution of this cool water indicates that it is being moved northward, as would be expected under the prevailing winds. The yellowfin appear to have been virtually absent from this newly upwelled water, although they were taken to the north and south of it (fig. 2). This is understandable if it is hypothesized that the newly upwelled water had not been in the euphotic zone long enough to develop a population of tuna forage.

The section on 130°W. longitude (fig. 3, table 1) rather closely resembles the 120°W. section in respect to the distribution of isotherms and the distribution of yellowfin, except that on the former the surface temperatures were somewhat higher and the yellowfin more abundant in the region of upwelled water. The slightly higher surface temperatures along 130°W. might indicate that the upwelling had been less intense or from shallower depths, or it might mean that the water had been in the photosynthetic zone for a longer period of time. If the latter were true, tuna feed might have accumulated, leading to the somewhat denser population of yellowfin evidenced by our catch rates.

Table 1.--Summary of the tuna catch, Smith cruise 18 (more complete data will be found in the appendix)

Station	Date	Noon position		Catch per 100 hooks			
		Latitude	Longitude	Yellowfin	Bigeye	Albacore	Skipjack
1	10-18-52	9°39'N	121°13'W	-	-	-	-
3	10-19-52	8°21'N	120°20'W	2.1	2.1	-	-
4	10-21-52	7°12'N	119°52'W	0.4	5.0	-	-
5	10-22-52	5°52'N	120°11'W	-	0.4	-	-
6	10-23-52	4°53'N	119°49'W	-	1.3	-	-
7	10-24-52	4°02'N	120°12'W	-	0.4	-	-
8	10-25-52	3°03'N	120°15'W	-	3.3	-	-
9	10-26-52	1°55'N	120°26'W	0.4	-	-	-
10	10-27-52	1°01'N	120°13'W	-	-	-	-
12	10-28-52	0°02'N	120°20'W	1.3	0.8	-	-
14	10-29-52	1°59'S	120°03'W	-	0.4	-	-
16	10-30-52	3°58'S	120°14'W	1.7	0.4	-	-
18	10-31-52	5°36'S	120°25'W	1.7	0.4	0.4	1.3
20	11-1-52	7°33'S	120°21'W	5.8	1.3	-	-
22	11-2-52	9°36'S	120°44'W	0.4	0.4	-	-
23	11-5-52	5°10'S	130°06'W	1.3	0.8	-	0.4
25	11-6-52	3°11'S	130°17'W	2.5	1.3	-	2.1
27	11-7-52	1°21'S	130°10'W	0.8	-	-	-
29	11-8-52	0°04'S	130°10'W	2.1	-	-	-
30	11-9-52	1°11'N	130°15'W	-	0.8	-	-
31	11-10-52	2°23'N	130°25'W	1.3	-	-	-
32	11-11-52	3°23'N	130°29'W	0.4	-	-	-
33	11-12-52	4°18'N	130°11'W	1.7	-	-	-
35	11-13-52	6°13'N	131°00'W	0.4	0.8	-	-
36	11-14-52	7°39'N	131°20'W	0.4	1.3	-	2.1
37	11-15-52	9°05'N	131°41'W	-	-	-	-

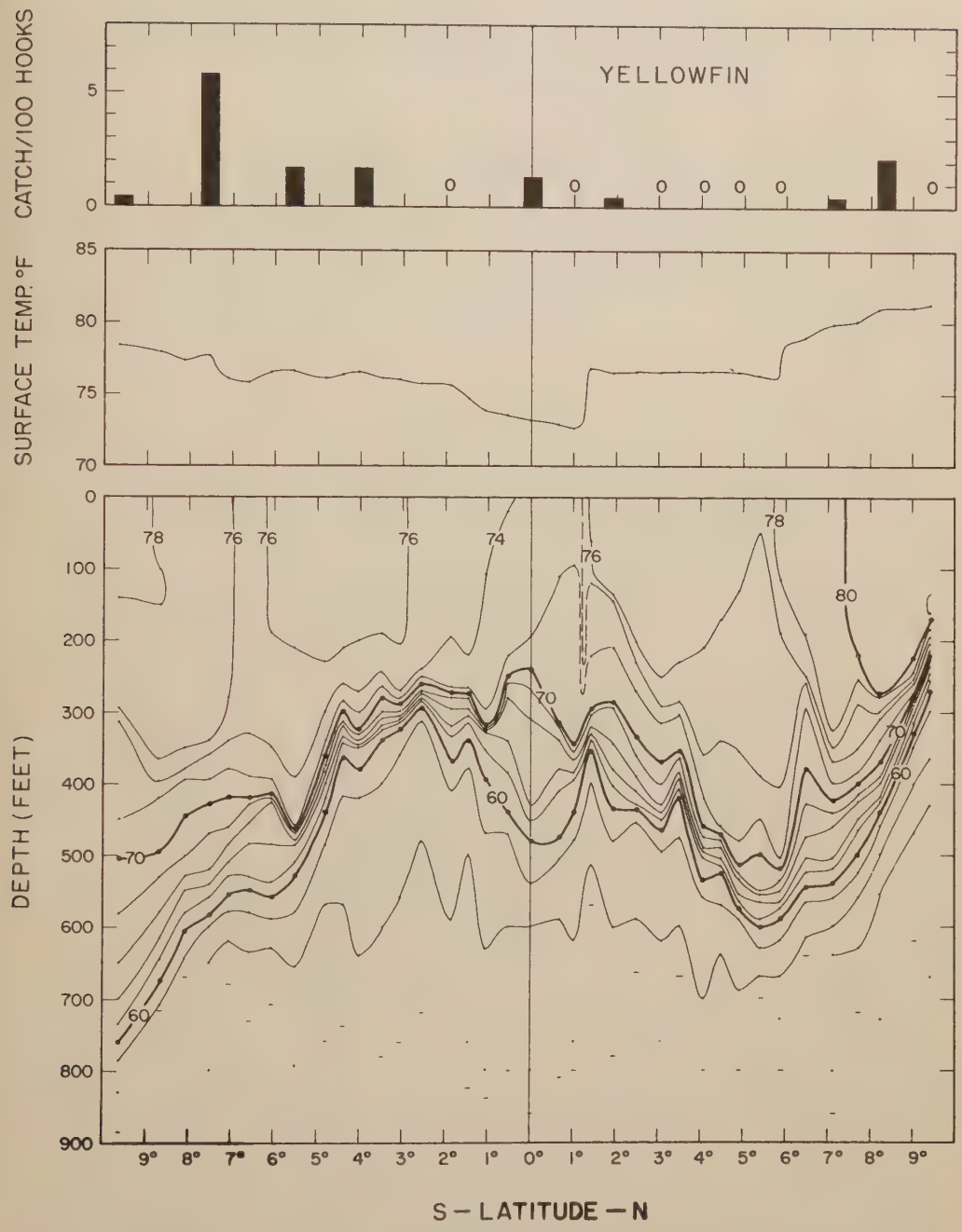

Figure 2.--Temperature section and yellowfin tuna catch along 120°W. longitude, October-November 1952. If no yellowfin were taken, a zero is shown in the upper panel.

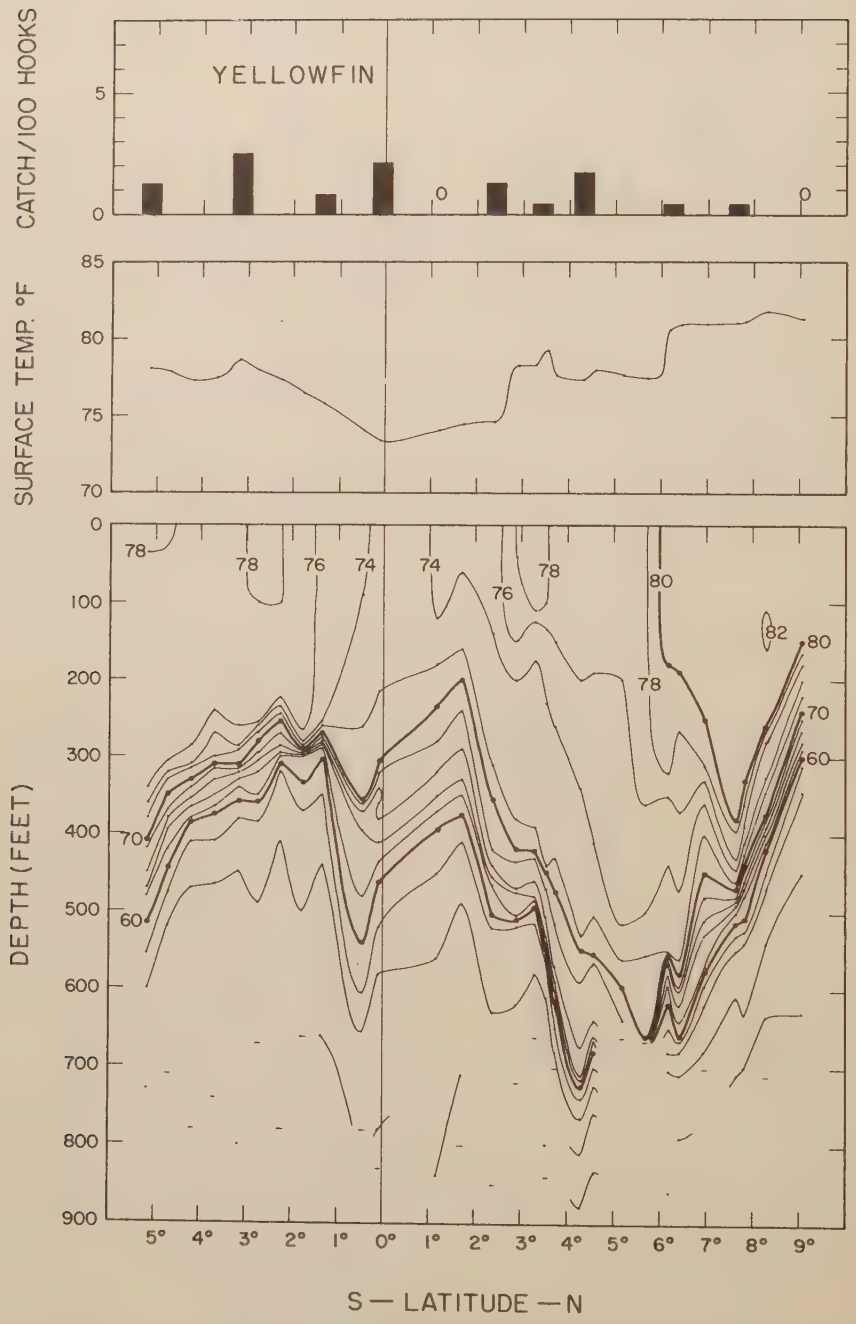

Figure 3.--Temperature section and yellowfin tuna catch along 130°W. longitude, November 1952. If no yellowfin were taken, a zero is shown in the upper panel.

The section on 140°W. (fig. 4, tables 2 and 3) gives the familiar picture of upwelling the Equator, although less intense than on 120°W. and 130°W., and indicates clearly a concen- ıtion of yellowfin in the South Equatorial Current north of the Equator. This section is not,)wever, strictly comparable to the other sections included in this report as it is made up of :ations from the Cavalieri cruise (1° to 7°N.) and from Manning cruise 12 (0° to 7°S.). The avalieri stations were fished from August 21 to September 6 and the Manning stations from ugust 31 to September 4, probably an inconsequential difference in time.

There were two sections along 150°W. longitude (figs. 5 and 6, tables 3 and 4). One as fished during the course of Manning cruise 12 in August 1952 and the second during Manning ruise 13 in October-November 1952. Both sections provide evidence of moderate upwelling and moderate concentration of yellowfin north of the Equator. Falling between these sections in me were the stations fished by the Cavalieri in September of 1952 along 150°W. longitude. It of interest to note that her catches (table 2) average considerably higher than those experienced month earlier and a month later by the Manning. These catches of the Cavalieri were lower,)wever, than those obtained along 150°W. longitude in September 1951 (Murphy and Shomura 953a).

Table 2.--Summary of the tuna catch, Cavalieri cruise 1
(more complete data will be found in the appendix)

Station	Date	Noon position		Catch per 100 hooks		
		Latitude	Longitude	Yellowfin	Bigeye	Skipjack
1	8-21-52	7°02'N	140°40'W	0.7	0.3	-
2	8-22-52	6°02'N	140°26'W	1.3	0.3	-
3	8-23-52	5°16'N	140°28'W	4.2	1.1	-
4	8-24-52	4°26'N	139°43'W	5.0	-	1.1
5	8-25-52	3°26'N	140°08'W	9.2	1.9	0.6
6	8-26-52	2°24'N	140°07'W	9.0	-	-
7	8-27-52	1°33'N	140°13'W	11.8	-	0.2
8	8-28-52	1°00'N	140°22'W	2.9	-	0.2
9	8-29-52	2°00'N	140°40'W	5.7	-	0.2
10	8-30-52	3°37'N	140°27'W	6.0	0.2	0.2
11	8-31-52	3°45'N	140°10'W	7.5	-	-
12	9-1-52	3°31'N	140°28'W	3.1	-	0.2
13	9-2-52	3°05'N	140°02'W	4.0	-	0.8
14	9-3-52	4°04'N	140°09'W	1.7	-	-
15	9-4-52	3°20'N	140°10'W	3.3	0.3	-
16	9-5-52	2°25'N	140°32'W	4.9	0.9	0.4
17	9-6-52	2°06'N	140°56'W	4.9	0.6	0.2
18	9-7-52	1°42'N	141°24'W	3.8	0.6	-
19	9-8-52	2°30'N	142°24'W	4.8	0.8	-
20	9-9-52	2°33'N	143°22'W	4.4	0.2	-
21	9-10-52	2°08'N	145°21'W	3.1	0.2	1.0
22	9-11-52	2°57'N	147°22'W	4.2	-	-
23	9-12-52	2°25'N	148°47'W	1.9	0.8	-
24	9-13-52	1°22'N	149°54'W	5.6	0.8	0.2
25	9-14-52	1°48'N	150°05'W	5.6	0.4	0.4
26	9-15-52	2°05'N	150°23'W	5.0	0.4	-
27	9-16-52	2°28'N	150°38'W	2.9	0.4	-
28	9-17-52	3°26'N	151°40'W	6.9	0.6	-
29	9-18-52	3°39'N	151°54'W	12.7	1.2	0.6
30	9-19-52	3°41'N	152°10'W	9.0	1.2	-
31	9-20-52	4°11'N	152°27'W	7.9	1.0	-

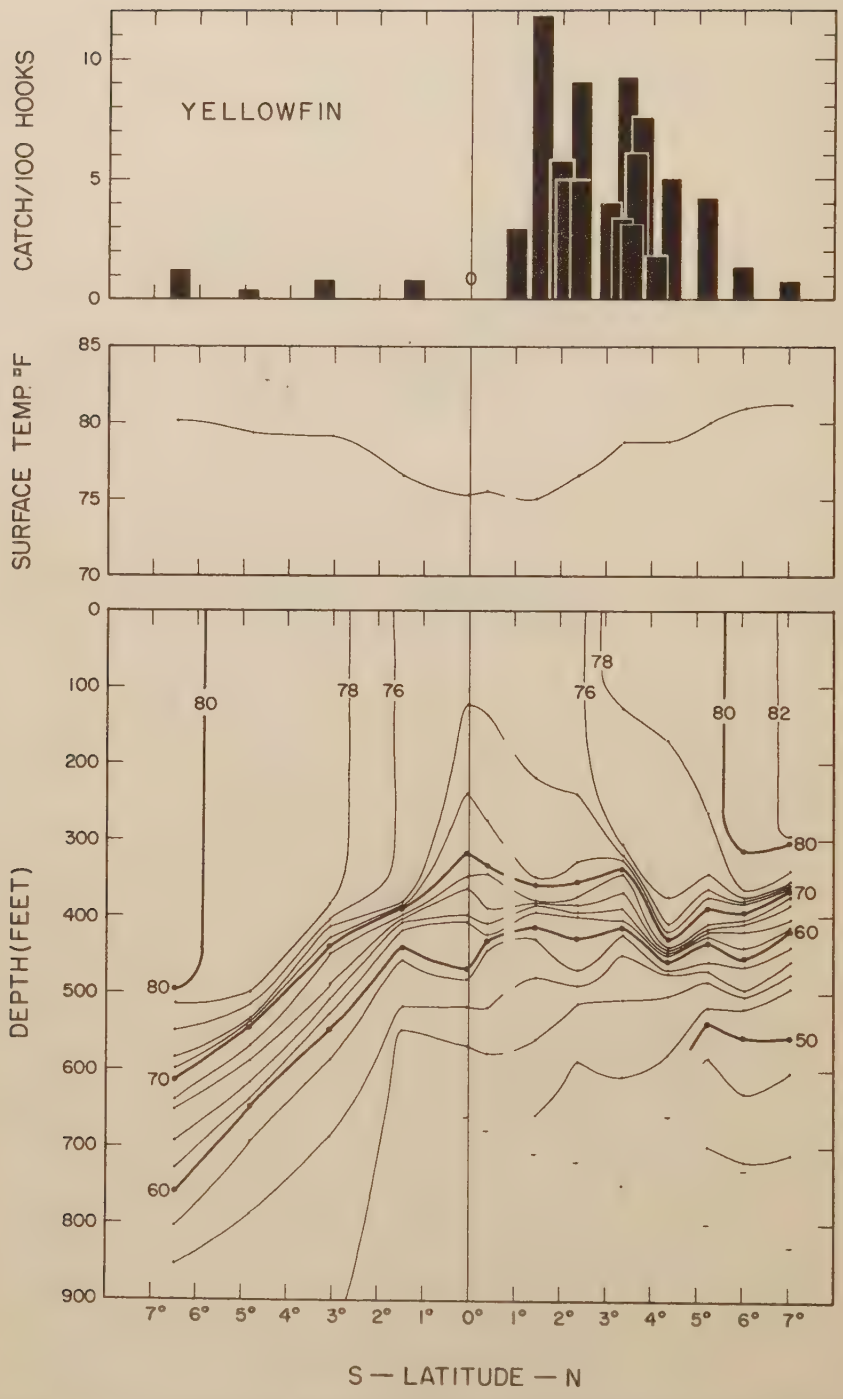

Figure 4.--Temperature section and yellowfin tuna catch along 140°W. longitude, August-September 1952. If no yellowfin were taken, a zero is shown in the upper panel. The break in the isotherms represents a 17-day interval between adjacent observations.

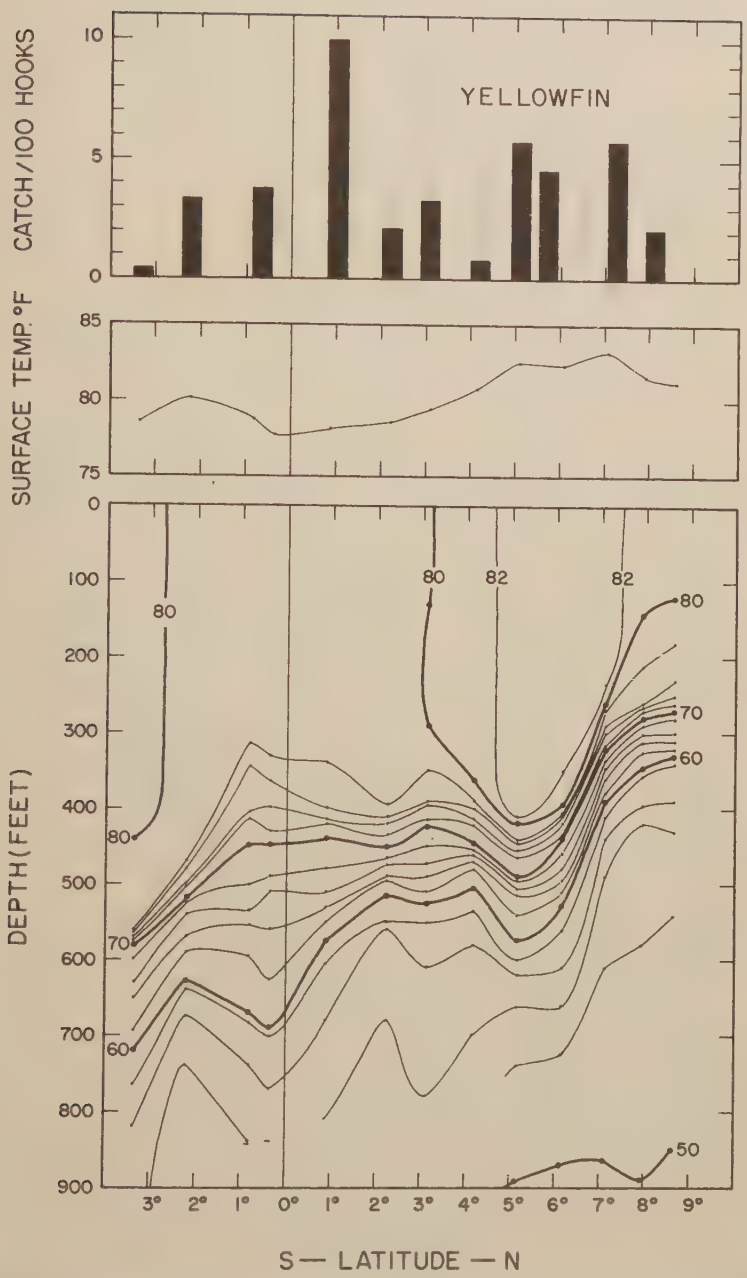

Figure 5.--Temperature section and yellowfin tuna catch along 150°W. longitude, August 1952.

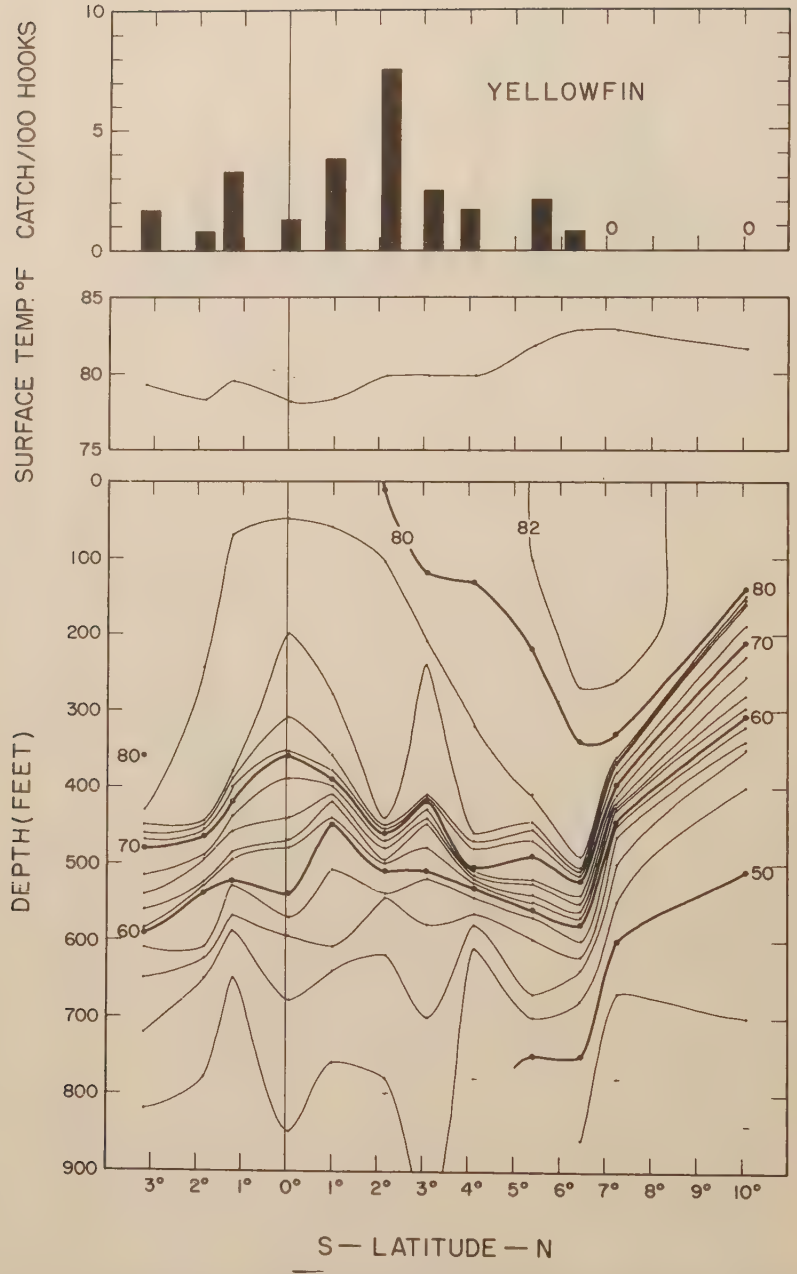

Figure 6.--Temperature section and yellowfin tuna catch along 150°W. longitude, October-November 1952. If no yellowfin were taken, a zero is shown in the upper panel.

Table 3.--Summary of the tuna catch, Manning cruise 12. (This tabulation includes only the catches at stations where 40 standard baskets (240 hooks) were fished in a manner designed to furnish an index of abundance. Other stations and experimental gear are considered elsewhere. More complete data will be found in the appendix.)

Station	Date	Noon position		Catch per 100 hooks			
		Latitude	Longitude	Yellowfin	Bigeye	Albacore	Skipjack
1	8-11-52	8°07'N	149°51'W	2.1	-	-	-
2	8-12-52	7°15'N	149°36'W	5.8	0.8	-	-
3	8-13-52	5°43'N	150°06'W	4.6	0.8	-	-
4	8-14-52	5°07'N	149°55'W	5.8	1.2	-	-
5	8-15-52	4°09'N	150°12'W	0.8	0.4	-	0.4
6	8-16-52	3°06'N	150°12'W	3.3	-	-	-
8	8-18-52	2°14'N	150°17'W	2.1	0.8	-	-
9	8-19-52	1°02'N	150°25'W	10.0	-	-	-
10	8-20-52	0°39'S	149°56'W	3.8	-	-	-
11	8-21-52	2°12'S	150°20'W	3.3	-	0.4	0.4
12	8-22-52	3°14'S	149°10'W	0.4	-	-	0.4
15	8-31-52	6°27'S	140°03'W	1.2	1.7	0.4	0.4
16	9-1-52	4°51'S	140°09'W	0.4	0.4	-	0.4
17	9-2-52	3°14'S	140°06'W	0.8	1.7	-	-
18	9-3-52	1°14'S	140°02'W	0.8	0.8	-	0.4
19	9-4-52	0°01'N	140°08'W	-	-	-	-

The section along 169°W. longitude in November 1952 (fig. 7, table 4) shows somewhat less evidence of upwelling in the vicinity of the Equator than do the sections to the east. Coincident with this, there was little indication of a yellowfin concentration to the north of the Equator. In general, the fish seem to have been more evenly spread over the entire section, with only a slight tendency to aggregate in the vicinity of the Equator.

In summary, the distribution of yellowfin tuna along the Equator in the central Pacific as revealed by the results of these four cruises is consistent with the distributions obtained during 1950 and 1951 in the late summer and fall. There is evidence, however, that the abundance was somewhat less during the early fall of 1952 than during the same period of 1951. During the earlier period a series of 10 stations over a rather wide area west of 150°W. longitude at approximately 2°N. latitude produced catches of yellowfin averaging over 12 fish per hundred hooks. During the fall of 1952 a larger number of stations in the same general locality resulted in only two catches near 12 per hundred hooks, and the average was about 6 yellowfin per hundred hooks. As yet there is no adequate explanation for this variation in the level of abundance.

Albacore

The cruises undertaken in the equatorial region provide only limited information on the distribution of albacore. This species is so important to the American tuna industry, however, that there is some justification for a preliminary statement of our findings. In general our surveys indicate that albacore are more abundant south than north of the Equator. This is shown by catches made along 169°W. longitude at about 5°S. in November 1952 (table 4), and by the good catches made at 5°-8°S. latitude along 169°W. and 180°W. longitude in February 1952 (Murphy and Shomura 1953b). Albacore appear to be more abundant to the west, as evidenced by the almost negative results along 120°W. and 130°W. (table 1), moderate results along 140°W. and 150°W. (tables 2 and 3), and relatively high catches along 169°W. and 180°W. (table 4 and Murphy and Shomura 1953b). The best catch was made during February 1952, when 6 albacore per 100 hooks

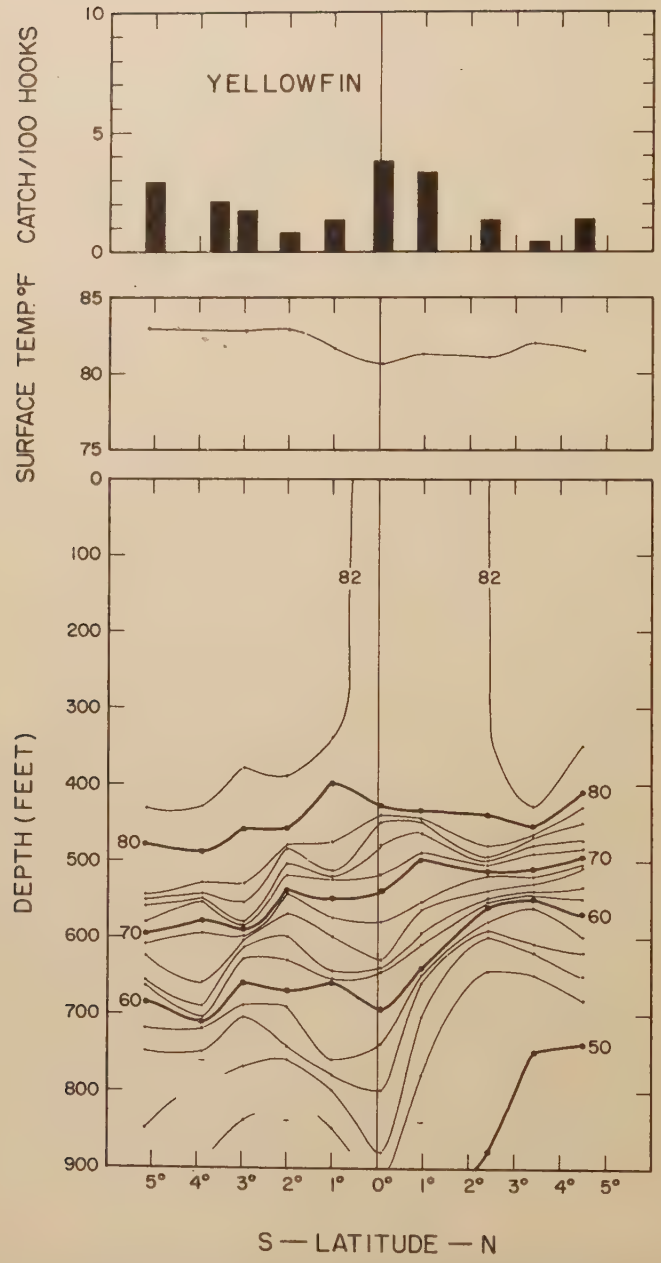

Figure 7.--Temperature section and yellowfin tuna catch along 169°W. longitude, November 1952.

Table 4.--Summary of the tuna catch, Manning cruise 13. (This tabulation includes only the catches at stations where 40 standard baskets (240 hooks) were fished in a manner designed to furnish an index of abundance. Other stations and experimental gear are considered elsewhere.)

Station	Date	Noon position		Catch per 100 hooks			
		Latitude	Longitude	Yellowfin	Bigeye	Albacore	Skipjack
1	10-17-52	21°11'N	158°25'W	-	-	1.7	-
2	10-19-52	17°16'N	156°32'W	-	0.8	-	-
3	10-21-52	13°30'N	155°24'W	-	1.7	-	0.4
4	10-23-52	10°03'N	153°35'W	-	0.4	-	0.4
6	10-25-52	7°06'N	152°11'W	-	1.7	-	-
7	10-26-52	6°17'N	152°28'W	0.8	0.4	-	-
8	10-27-52	5°34'N	152°26'W	2.1	-	-	-
9	10-28-52	4°00'N	152°20'W	1.7	0.4	-	-
10	10-29-52	3°13'N	152°05'W	2.5	1.3	-	-
11	10-30-52	2°15'N	151°19'W	7.5	-	-	-
14	11-3-52	1°00'N	151°26'W	3.8	0.4	-	0.8
15	11-4-52	0°03'N	150°39'W	1.3	-	-	0.4
16	11-5-52	1°14'S	150°51'W	3.3	-	-	3.8
17	11-6-52	1°52'S	151°46'W	0.8	-	-	-
18	11-7-52	3°06'S	152°15'W	1.7	-	0.4	-
19	11-19-52	5°00'S	170°08'W	2.9	0.8	2.9	-
20	11-20-52	3°36'S	170°02'W	2.1	-	1.3	-
21	11-21-52	2°57'S	169°49'W	1.7	-	-	0.4
22	11-22-52	1°59'S	169°44'W	0.8	0.4	0.8	0.8
23	11-23-52	1°00'S	169°27'W	1.3	-	-	0.4
24	11-24-52	0°04'N	168°48'W	3.8	-	-	0.4
25	11-25-52	1°03'N	168°52'W	3.3	-	-	1.3
26	11-26-52	2°24'N	168°44'W	1.3	-	-	-
27	11-27-52	3°30'N	168°49'W	0.4	-	-	0.4
28	11-28-52	4°30'N	168°17'W	1.3	-	-	-

were taken at 5°S. latitude, 180°E. longitude. The absolute size of the catch obtained on these surveys cannot, however, be regarded as indicative of the potential of the population as the gear was designed for yellowfin fishing and probably was not operated in a manner conducive to the most efficient capture of albacore.

Japanese Longline Fishing

There was a renewal of Japanese commercial fishing in the western part of the central Pacific during the latter half of 1952. Some of their catches during the period covered by this report (August-November 1952) in the western portion of the area under consideration are given in tables 5 and 6. In general they show the same abundance of tunas as our experimental fishing, with bigeye dominating north and yellowfin south of 5°N. latitude. Further, it is evident that the relatively low catch rates experienced by us at 169°W. longitude were representative as far west as 180° longitude.

Certain portions of the data in table 6 are of special interest because they afford an opportunity for a direct comparison of our catch rates with commercial fishing results. Figure 8 shows the catches of the Manning along 169°W. longitude in comparison with Japanese catches (averaged by degrees of latitude) made between 168°W. and 175°W. longitude at almost the same

Table 5.--Summary of Japanese longline fishing in the central Pacific in 1952 (adapted from Kanagawa Prefecture Fishery Experiment Station, Monthly Report Nos. 3-6)

Month	Latitude	Longitude	Number of hooks	Catch per 100 hooks					
				Yellow-fin	Big-eye	Alba-core	Skip-jack	Spear-fishes	Sharks
July	6°-12°N	164°-178°W	189,770	0.23	2.29	0.04	0.32	1.41	0.64
August	0°- 6°N	160°-177°W	81,750	1.71	0.91	0.04	0.08	1.14	0.59
	8°-20°N	161°-180°W	237,190	0.17	2.47	0.07	0.13	1.37	1.13
September	3°- 4°N	171°-178°W	33,120	2.77	0.29	0.02	0.06	0.79	0.66
	7°-12°N	158°-179°W	124,000	0.22	1.83	0.04	0.14	1.01	0.81
October	7°-11°N	173°-180°W	154,340	0.35	1.80	0.09	0.03	0.77	0.78
	3°- 6°N	167°-179°W	107,090	2.79	0.68	0.02	0.31	1.01	0.73
November	7°-11°N	169°-179°W	101,954	0.27	2.22	0.01	0.08	0.65	0.97
	0°- 5°N	160°-179°W	111,780	1.83	0.78	0.06	-	0.80	0.98

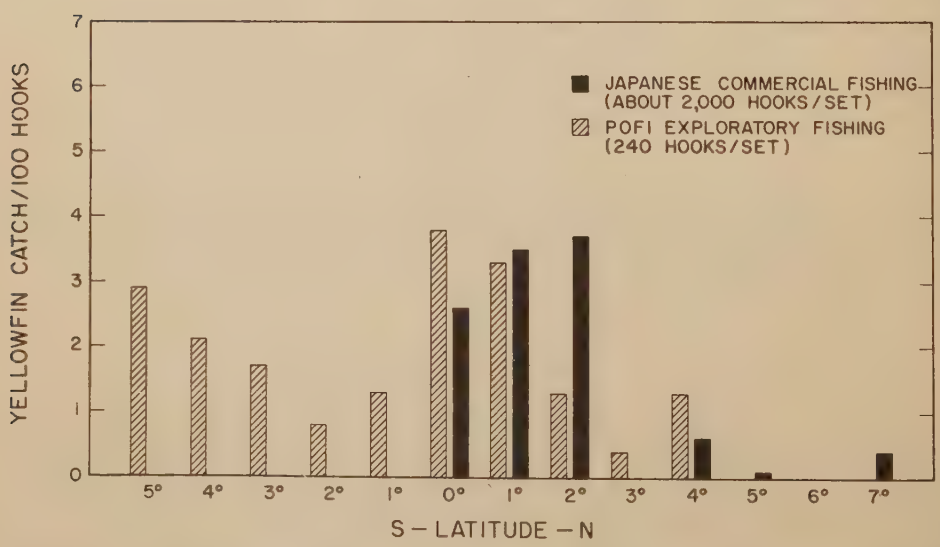

Figure 8.--Comparison between the catch rates of Japanese commercial sets and POFI exploratory sets. The bars representing Japanese fishing are based on data in table 6. The bars representing POFI fishing are based on results of fishing along 169°W. longitude during Manning cruise 13 (table 4).

Table 6.--Records of individual commercial longline sets by two Japanese vessels in the central Pacific in 1952 (unpublished data furnished by Mr. Toshizō Nomura of the Kanagawa Prefecture Fisheries Experiment Station)

Date	Latitude	Longitude	Number of hooks	Catch per 100 hooks			
				Yellowfin	Bigeye	Albacore	Skipjack
Vessel A							
27 Oct.	5°20'N	175°10'W	1,560	0.12	0.57	-	-
28 "	4°29'N	175°15'W	1,560	0.57	0.45	-	-
3 Nov.	6°38'N	173°08'W	1,560	0.12	1.28	-	-
4 "	6°50'N	171°40'W	1,560	0.77	2.76	-	-
5 "	6°38'N	169°20'W	1,560	0.51	3.46	-	-
6 "	7°20'N	165°01'W	1,560	0.38	1.92	-	-
7 "	6°30'N	166°00'W	1,560	0.64	2.12	0.26	-
8 "	6°54'N	166°38'W	1,560	1.28	1.67	-	-
9 "	2°28'N	166°20'W	1,950	2.00	0.10	-	-
10 "	1°40'N	168°30'W	1,950	5.13	0.62	-	-
11 "	1°48'N	168°30'W	1,950	3.95	0.41	-	-
13 "	0°53'N	169°35'W	1,950	5.23	0.15	-	-
14 "	0°56'N	170°30'W	1,950	1.74	0.62	-	-
15 "	0°17'N	169°20'W	1,950	0.26	0.15	0.10	-
17 "	0°24'N	169°55'W	1,950	4.10	0.31	-	-
18 "	0°57'N	170°07'W	1,950	3.18	0.41	-	-
19 "	0°35'N	169°55'W	1,950	2.51	0.21	0.05	-
20 "	0°11'N	170°30'W	1,950	3.54	0.21	0.10	-
21 "	0°35'N	170°10'W	1,950	3.90	0.41	0.10	-
22 "	0°36'N	170°07'W	1,950	4.67	0.31	0.05	-
23 "	0°37'N	170°03'W	1,950	3.49	0.21	0.15	-
Vessel B							
29 Oct.	6°55'N	178°18'E	1,830	0.49	1.80	-	0.11
30 "	7°15'N	179°16'E	1,830	0.44	1.42	-	0.44
31 "	7°00'N	178°53'E	1,830	0.11	2.13	-	0.55
2 Nov.	10°27'N	179°10'E	1,830	0.16	0.71	-	0.11
4 "	6°51'N	178°58'W	1,830	0.11	2.19	-	0.11
5 "	6°58'N	178°33'W	1,830	0.22	2.68	-	0.05
6 "	6°52'N	178°21'W	1,830	0.27	1.91	-	0.16
7 "	7°00'N	178°36'W	1,830	0.27	2.51	-	0.16
8 "	7°07'N	178°33'W	1,830	0.05	2.79	-	0.16
9 "	6°59'N	178°39'W	1,830	0.27	3.06	-	0.16
10 "	6°55'N	178°45'W	1,830	0.16	2.51	-	0.27
11 "	6°57'N	178°47'W	1,830	0.05	1.09	-	-
12 "	7°03'N	178°39'W	1,830	0.27	1.75	-	-
13 "	6°58'N	178°35'W	1,830	0.38	1.75	-	0.16
14 "	7°00'N	178°44'W	1,464	0.14	0.89	-	0.27
15 "	7°15'N	178°55'W	1,400	0.07	3.43	-	0.36
16 "	7°40'N	179°07'W	1,120	0.80	0.71	-	0.27

time. The Japanese catches are of the same general magnitude as ours but are less variable. The variability of our catches can probably be attributed to the small amount of fishing effort represented. From these data it can be concluded that the catch rates obtained by small experimental sets of gear are representative of what might be expected from a large commercial set.

SIZE OF TUNAS

Length frequencies of the yellowfin tuna taken on the nine sections (table 7) suggest a tendency for the catches to be composed of larger fish toward the eastern end of the survey area, although the difference is not as pronounced as indicated in earlier surveys (Murphy and Shomura 1953b). A recapitulation of data for yellowfin is given in table 7 and in figure 9, based on data in Murphy and Otsu (1954), Murphy and Shomura (1953a, b), and table 7. This clearly shows that longline yellowfin increase in size from west to east. The simplest explanation of this size differential is that the growth rate of the yellowfin changes across the Pacific. This is most likely a reflection of the relative availability of food in the several areas.

Table 7.--Length frequencies of yellowfin tuna taken by longline fishing gear

Length	Smith cruise 18		Manning cruise 12		Cavalieri cruise 1			Manning cruise 13	
	120°W.	130°W.	140°W.	150°W.	140°W. 1/	145°W. 2/	150°W. 3/	150°W.	169°W.
cm									
42	1	-	-	-	-	-	-	-	-
47	-	-	-	-	-	-	-	-	-
52	-	-	-	-	-	-	-	-	-
57	-	-	-	-	-	-	-	-	-
62	-	-	-	-	-	-	-	-	-
112	-	-	-	-	3	-	-	1	-
117	-	1	-	-	-	-	1	1	1
122	1	1	1	2	2	-	1	-	3
127	2	2	1	3	2	1	1	1	2
132	1	2	1	9	12	3	11	4	8
137	6	3	1	17	23	13	40	11	18
142	3	1	1	33	47	12	40	17	5
147	5	2	-	13	40	13	37	16	7
152	4	1	-	11	51	18	30	4	3
157	5	2	-	5	62	21	13	2	-
162	3	1	1	3	39	12	3	1	-
167	2	5	-	1	21	4	1	-	-
172	-	2	-	-	6	-	-	1	-
177	-	-	-	-	-	1	-	-	-

1/ Stations 1-19
2/ Stations 20-22
3/ Stations 23-31

This proposal is compatible with our estimates of the amount of upwelling in the three areas figured. In the westernmost area (140°E. to 170°E. longitude) there is no evidence that upwelling takes place along the Equator (Murphy and Otsu 1954). In the central area (180° to 150°W. longitude) moderate to strong upwelling is a persistent feature of the hydrography along the Equator (Austin 1954, Cromwell 1953, Murphy and Shomura 1953a, b, and figs. 5-7 of this report). In the easternmost area (145°W. to 120°W. longitude) upwelling appears to be very intense, at least at times (figs. 2-3).

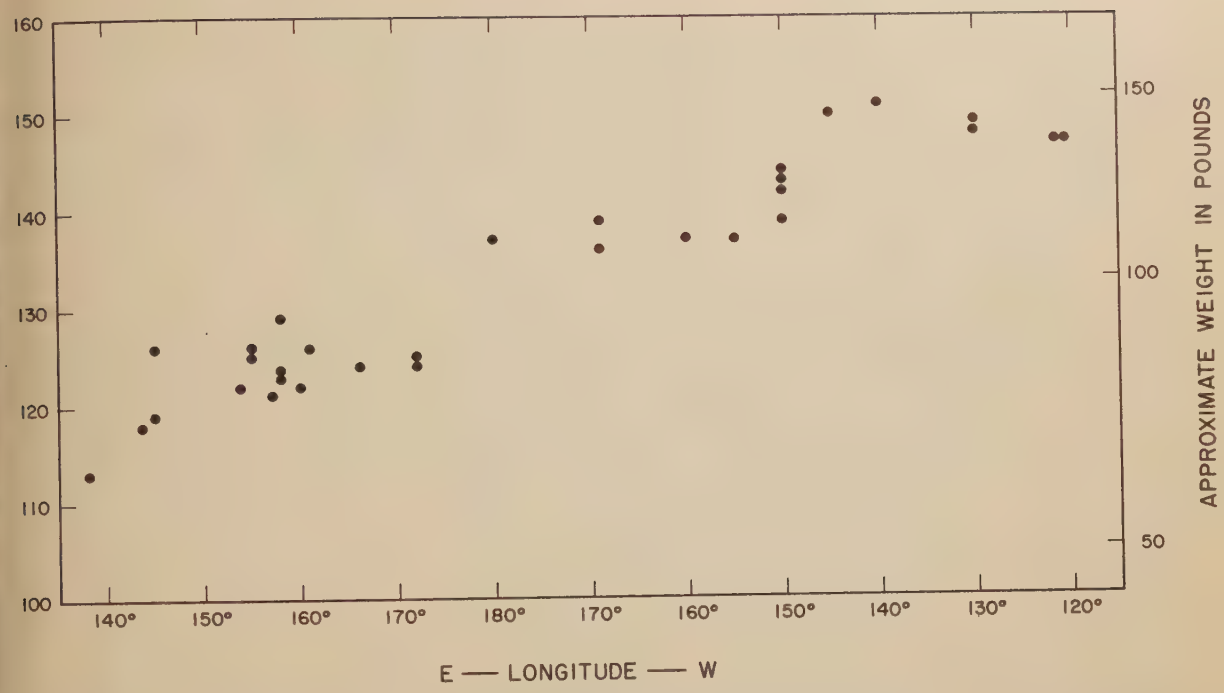

Figure 9.--Mean lengths of samples of longline-caught yellowfin plotted against longitude of capture.

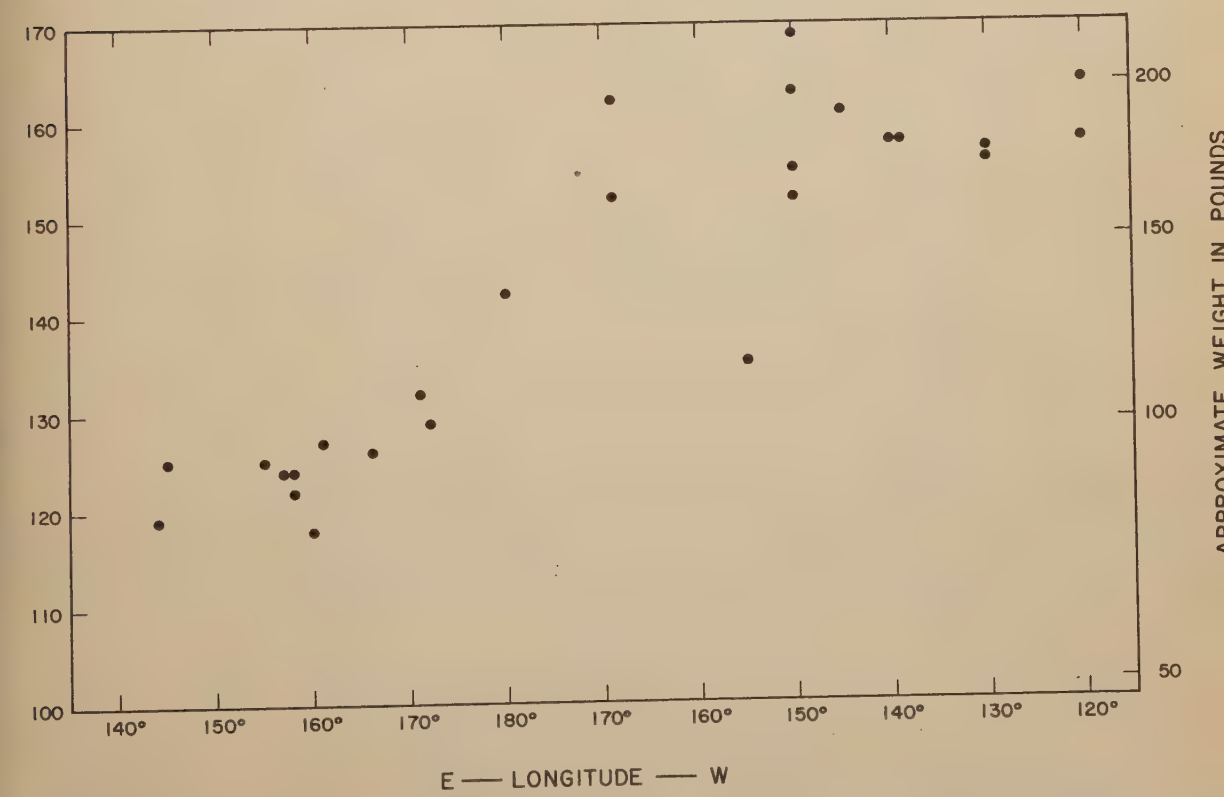

Figure 10.--Mean lengths of samples of longline-caught bigeye tuna plotted against the longitude of capture.

The length frequencies of bigeye tuna show the same marked increase in size from west to east as do the yellowfin (fig. 10--this figure is based on the same sources as fig. 9, and includes the measurements from the cruises noted in table 8). There is a suggestion of two size levels in figure 10, with fish west of 180° considerably smaller than those to the east but considering the relatively small number of fish in each sample, the steep gradient centering at 180° may be an artifact.

Table 8.--Length frequencies of bigeye tuna taken by longline fishing gear

Length	Smith cruise 18		Manning cruise 12		Cavalieri cruise 1			Manning cruise 13	
	120°W.	130°W.	140°W.	150°W.	140°W. 1/	145°W. 2/	150°W. 3/	150°W.	169°W.
cm									
57	-	-	-	-	-	-	-	1	-
87	-	-	-	-	-	-	1	-	-
92	-	-	-	-	-	-	-	1	-
97	-	-	-	-	-	-	-	-	-
102	-	1	-	-	-	-	-	1	-
122	1	-	-	-	-	-	-	-	-
127	1	-	-	-	1	-	-	-	-
132	-	-	1	1	1	-	-	2	-
137	1	-	-	-	2	-	-	1	-
142	1	-	-	-	1	-	1	1	-
147	6	3	1	1	-	-	1	2	-
152	1	1	1	1	2	3	1	2	-
157	4	1	3	3	3	3	2	3	-
162	10	1	2	2	3	2	3	1	1
167	4	1	1	1	3	1	4	2	1
172	2	1	2	2	1	1	2	4	1
177	-	2	-	-	-	1	6	1	-
182	2	-	-	-	2	-	1	1	-
187	1	1	-	-	1	-	-	1	-
192	-	-	-	-	-	-	-	1	-
197	-	-	-	-	-	-	-	-	-

1/ Stations 1-19
2/ Stations 20-22
3/ Stations 23-31

The samples of albacore and skipjack are inadequate for the type of analysis performed on the yellowfin and bigeye. They are, however, useful in another respect, because they indicate that the longline will take relatively small fish (table 9). The capture of albacore and skipjack is good evidence that the absence of appreciable numbers of small yellowfin and bigeye from the longline catches is due to their absence from the habitat fished on our cruises to the Equator rather than to gear selection.

SEX RATIOS OF THE TUNAS

Puzzling discrepancies appear in the sex ratios of tuna taken on the longline. In previous reports we have noted the fact that males predominate in the catches of bigeye and yellowfin (Murphy and Shomura 1953a, b). With respect to yellowfin, Nakamura (1949) noted that catches made in the East Philippine Sea had equal representation of the sexes up to 122 cm.

bout 77 pounds), and that there were more males among the larger fish. The present longline mples (table 10) also contain more male yellowfin and bigeye.

Sufficient material is now on hand for a preliminary analysis of the sex discrepancy the yellowfin tuna. We have used samples from the Japanese mothership operations of 1950 id 1951 (Murphy and Otsu 1954), POFI longline cruises (Murphy and Shomura 1953a, b), POFI rebait fishing and trolling in the central Pacific, and the cruises covered in this report (table).

Table 9.--Length frequencies of albacore and skipjack tuna taken by longline fishing gear

Length	Albacore		Skipjack			
	Manning 12	Manning 13	Manning 12	Cavalieri 1	Manning 13	Smith 18
cm						
35	-	-	-	1	-	-
58	-	-	-	-	1	-
64	-	-	-	-	-	1
66	-	-	-	-	-	-
67	-	-	-	1	-	1
68	-	-	-	-	-	3
69	-	-	-	-	-	-
70	-	-	-	1	-	-
71	-	-	-	-	-	-
72	-	-	-	-	-	-
73	-	-	-	-	1	1
74	-	-	-	2	-	-
75	-	-	1	2	2	-
76	-	-	-	1	2	2
77	-	-	-	3	3	-
78	-	-	-	2	3	1
79	-	-	2	4	6	2
80	-	-	2	4	7	1
81	-	-	3	2	2	1
82	-	-	-	2	1	1
89	-	1	-	-	-	-
90	-	-	-	-	-	-
91	-	1	-	-	-	-
92	1	-	-	-	-	-
93	-	2	-	-	-	-
94	-	1	-	-	-	-
95	-	2	-	-	-	-
96	-	3	-	-	-	-
97	-	-	-	-	-	-
98	-	1	-	-	-	-
99	-	2	-	-	-	-
100	-	-	-	-	-	-
101	-	1	-	-	-	-
102	-	-	-	-	-	-
103	-	1	-	-	-	-
104	-	1	-	-	-	-
105	-	1	-	-	-	-
106	-	1	-	-	-	-

Table 10.--Summary of frequency of males and females in three species of tuna

Cruise	Species	Number of males	Number of females	Ratio of males:females
Smith cruise 18	Yellowfin	33	19	1:0.6
	Bigeye	30	13	1:0.4
	Skipjack	5	2	1:0.4
	Albacore	-	1	- -
Cavalieri cruise 1	Yellowfin	439	167	1:0.4
	Bigeye	42	15	1:0.4
	Skipjack	12	13	1:1.1
Manning cruise 12	Yellowfin	65	45	1:0.7
	Bigeye	15	7	1:0.5
Manning cruise 13	Yellowfin	77	43	1:0.6
	Bigeye	19	9	1:0.5
	Albacore	7	11	1:1.6
	Skipjack	15	12	1:0.8

In analyzing the length frequencies of the yellowfin, the samples were combined into three groups corresponding to the samples from the western, central, and eastern equatorial Pacific. These combined samples (fig. 11) indicate essentially the same type of sex ratio discrepancy noted by Nakamura, namely equal representation up to a certain size, followed by a preponderance of males in the larger categories. It is interesting to note that as the average size of the fish within each sample increases, the length at which males begin to predominate also increases (fig. 11).

In the "western region" (fig. 11), males begin to predominate at about 122 centimeters, which is approximately the size noted by Nakamura (1949) for fish taken at the western end of the zone. In the "central region" males do not predominate until a size of 137 cm. is reached. In the "eastern region" the difference in the ratio appears at about 147 cm., although the sample is inadequate for clear delineation.

It is interesting to speculate on the cause of the discrepancy in the sex ratio of the larger fish. One possibility is differential growth, but if this were responsible, there should be a preponderance of females in some of the smaller size categories. Another possibility is that females do not feed while spawning and are therefore removed from the fishable population for an unknown period of time. However, it appears that if females ceased feeding for a long enough period to produce the discrepancies in figure 11, they would have a slower growth rate than the males, and as already pointed out, differential growth appears untenable. A third hypothesis is that females during a portion of their life occupy a different geographical range from the males. This seems unlikely in the absence of samples showing a preponderance of females. The final and most credible hypothesis is that there is differential mortality between the sexes after a certain size (age) is attained.

VERTICAL DISTRIBUTION OF TUNAS

In earlier reports we pointed out that yellowfin, bigeye, and albacore tuna were usually caught at a greater rate on the deeper fishing hooks of a set of longline gear (Murphy and Shomura 1953a, b). This was in general agreement with the findings of various Japanese workers

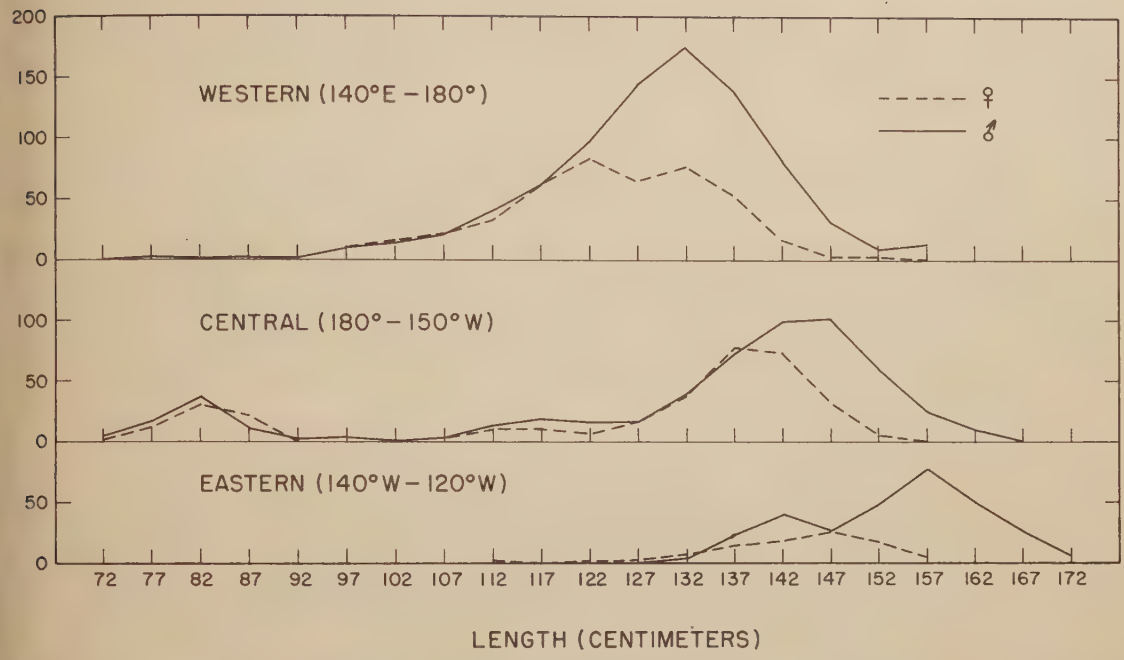

Figure 11.--Length frequencies of male and female yellowfin tuna from three regions of the equatorial Pacific.

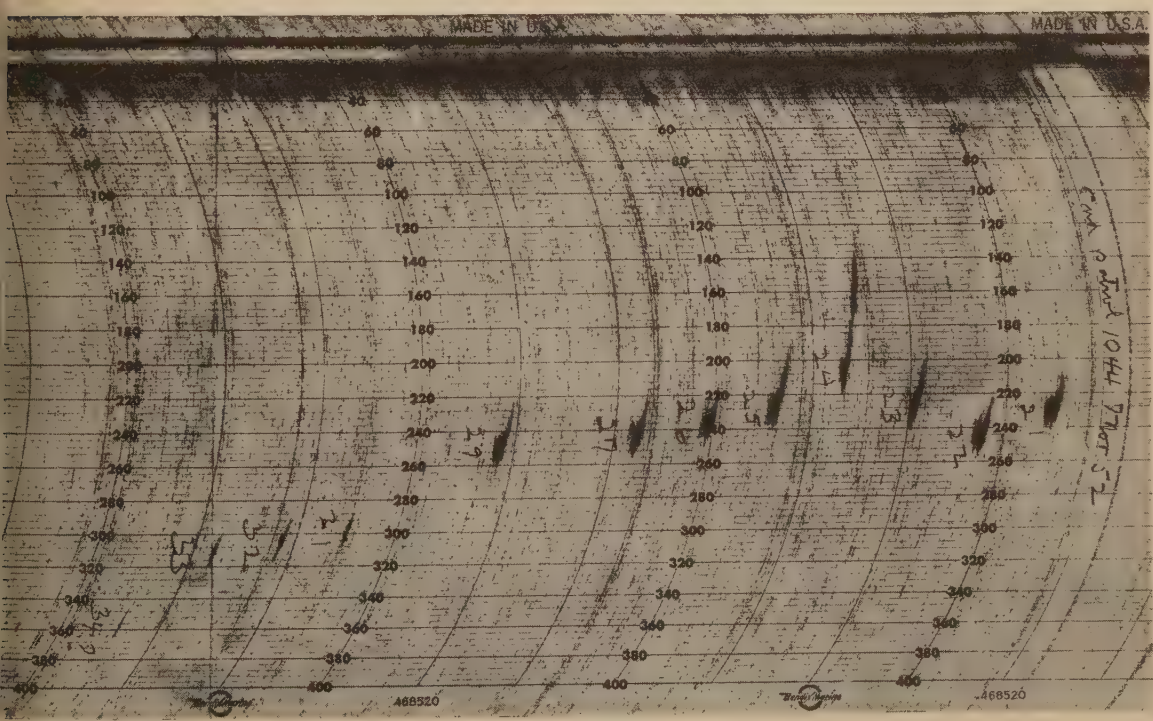

Figure 12.--A series of depth recorder traces of the main line, station 27, Smith cruise 18.

e.g. Nakamura (1949). These conclusions were necessarily based on a consideration of relative hook depth, since no means were available to measure the actual depth at which the line fished. Subsequent effort on this problem has been devoted to a continuation of the study of the relative depth of capture, and attempts have also been made to measure the absolute depth at which the line fishes.

The most successful method of ascertaining the line depth has been the measurement of the depth of the center of each section of the main line with a Bendix Depth Recorder, a method suggested by W. F. Royce. The depth of the line was usually measured about 3 or 4 hours after setting by conning the ship parallel to the line at various distances on either side of the line of buoys until a trace of the main line was obtained on the recording paper. After the first trace appeared, it was usually possible to locate other sections of the line by conning the ship so that it passed over the same position relative to other buoys. A series of good records is shown in figure 12, consisting of traces from a series of baskets near the end of a 40-basket set. The progressively increasing depth of the traces is a reflection of the increasing sag of the main line, caused by the closing in of the end buoys.

In connection with the problem of measuring the depth of the line, attempts were made to measure the distance between buoys in order to ascertain the relationship between the buoy distance and the depth fished.[2/] On Smith cruise 18 the average buoy interval was estimated from the setting speed and time, dividing the number of baskets into the distance covered over the sea surface. On this cruise the average buoy interval was also measured by radar. This was accomplished by placing a target on one of the buoys 2 or 3 baskets from the end of the entire set and measuring the total distance between the center of the set and the radar target. This measurement appeared to be fairly reliable as the line was usually quite straight. The measurements by radar taken some 4 hours after the gear was set were in close agreement with the distance between buoys as estimated from the setting speed and time (table 11). Thus, the latter method furnishes a good estimate of the average buoy interval during the course of the fishing day and provides a useable figure from which to estimate the theoretical maximum depth.

It is quite evident from comparison of the theoretical depths and the measured depths (tables 11 and 12) that on these two cruises there was considerable streaming of the line, which probably was caused by a current differential between the surface water and the thermocline. This was also evident in the field, as the center of the sag of the main line was nearly always located at a considerable distance from a straight line between any two buoys.

The correlation between the theoretical depth as determined from the average buoy interval and the actual depth measured with the depth recorder is not particularly close ($r = 0.315$ for the combined data of tables 11 and 12). Part of this can be laid to a lack of precision in measuring the two variables (line depth and buoy interval), and part can be laid to changing conditions with respect to the speed of the surface current from station to station, i.e., failure to control the factors other than buoy distance that determine the actual depth the line fished. Another difficulty, which may in part be responsible for the low correlation between buoy distance and depth, is indicated by the suggestion of a negative relation between the number of successful depth recorder traces and the average depth at each station (table 11). This suggests that as the line goes deeper the chances of obtaining a legible record on the depth recorder are lessened. This was also indicated in the field by the progressive faintness of the traces as the apparent depth of the line increased. That there is a real relation between buoy distance and line depth is indicated by the progressive deepening of the traces in figure 12. These traces were obtained near the end of a set, where the buoys supporting successive baskets were progressively closer together.

It has not yet been possible to establish any relationship between the catch and the data on line depth, nor between the relative depth of the greatest catch and either the depth of the

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2/ The theoretical fishing depth is, of course, fixed by the buoy interval, since the line should hang in a catenary. Curves of theoretical fishing depth versus buoy interval are given in Murphy and Shomura (1953a).

ermocline or the measured depth of the line. However, summaries of the catches of the four uises by station and relative hook depth indicate that on three cruises (Manning cruises 12 and and Smith cruise 18; tables 13, 15, and 16) there were no significant differences in the catch f yellowfin among the three hook levels, although the shallower hooks caught fewer fish. On o of these cruises Bendix depth recorder records (tables 11 and 12) indicate there was consider- ble current-induced streaming of the line. This would, of course, reduce the depth differential etween shallow and deep hooks, and less difference in catch should be expected. On the Cava- eri cruise (table 14) yellowfin were taken in significantly greater numbers on the deep hooks, it there are no records of the depths fished by the line.

On all four cruises more bigeye were taken on the deeper hooks, but the differences ere statistically significant on only two (Cavalieri and Manning cruise 13). The only cruise on hich albacore were taken in any number (Manning cruise 13, table 15) indicated a much greater atch on the deepest hooks.

Table 11.--Measurements of buoy interval and line depth, Smith cruise 18

Station	Buoy interval (feet)		Echo sounder measurements of line depth (feet)				Theoretical mean[1/]
	Setting distance	Radar measurement	Number of observations	Minimum	Maximum	Mean	
1	950	943	2	316	332	324	430
3	950	960	5	224	336	285	430
4	950	820	1	-	-	280	430
5	955	950	7	168	232	186	430
6	930	-	1	-	-	176	440
7	965	-	-	-	-	-	420
8	535	560	1	-	-	204	590
9	850	860	10	172	196	178	480
10	995	1105	12	172	212	191	410
12	987	960	8	212	224	220	410
14	990	950	3	220	248	233	410
16	1040	1055	-	-	-	-	380
18	1035	1025	-	-	-	-	380
20	1030	1030	1	-	-	248	390
22	935	960	1	-	-	260	440
23	1020	-	2	288	292	290	390
25	1045	1008	8	248	368	322	370
27	1080	1045	18	192	352	250	350
29	1070	1035	-	132	176	162	360
30	1105	1140	8	160	240	191	330
31	1120	1150	7	124	136	131	320
32	1120	1120	3	128	132	131	320
33	1120	1030	8	132	268	212	320
35	1190	-	7	160	192	176	250
36	1185	-	1	-	-	240	250
37	1200	-	6	120	180	147	240

1/ Based on the mean setting buoy distance as estimated from the setting speed and time.

Table 12.--Measurements of buoy interval and line depth, Manning cruise 12

Station	Setting distance in feet	Echo soundings of line depth in feet				Theoretical mean[1/]
		Number of observations	Minimum	Maximum	Mean	
1	1135	-	-	-	-	300
2	1095	-	-	-	-	340
3	1095	11	164	246	220	340
4	1055	7	210	254	232	370
5	1095	-	-	-	-	340
6	1055	-	-	-	-	370
8	1100	8	236	272	247	330
9	1125	4	88	132	112	310
10	1090	8	126	172	153	340
11	992	7	126	216	162	410
12	1200	1	-	-	-	230
15	1100	6	238	292	274	330
16	900	5	336	372	357	460
17	1040	5	270	294	286	380
18	820	-	-	-	-	490
19	1025	6	132	140	137	390

1/ Based on the mean buoy distance as estimated from the setting speed and time.

Table 13.--Yellowfin and bigeye tuna catch by relative hook depth, Manning cruise 12

Species	Station[1/]	Shallow	Intermediate	Deep	χ^2
Yellowfin	1-2	9	4	6	2.001
	3-4	9	13	3	6.082*
	5-6, 8	3	7	5	1.600
	9	6	10	7	1.130
	10-11	6	6	5	0.118
	12, 15-18, 21-22	6	10	8	1.000
	Total	39	50	34	11.931 Total χ^2 (d.f. 12) 3.268 Pooled χ^2 (d.f. 2) 8.663 Interaction χ^2 (d.f. 10)
Bigeye	All stations	5	9	11	2.241 Pooled χ^2 (d.f. 2)

1/ Stations combined to give minimum expected catches of five.
* Significant at the 0.05 level.

Table 14.--Yellowfin and bigeye tuna catch by relative hook depth, Cavalieri cruise 1

Species	Station[1/]	Shallow	Intermediate	Deep	χ^2
Yellowfin	1-3	4	10	7	2.571
	4	8	5	5	1.000
	5	8	11	14	1.636
	6	8	13	12	1.273
	7	5	25	19	12.901**
	8-9	15	10	11	1.167
	10	4	11	10	3.441
	11	9	15	10	1.824
	12-13	6	12	13	2.775
	14-15	6	7	7	0.100
	16	5	8	9	1.182
	17	7	11	5	2.435
	18	2	9	6	4.350
	19	8	9	6	0.608
	20	7	6	8	0.286
	21	3	3	9	4.800
	22	3	9	8	3.098
	23-24	9	13	14	1.167
	25	5	9	13	3.556
	26	5	11	8	2.250
	27	5	6	4	0.400
	29	12	19	30	8.100*
	31	8	14	16	2.736
	Total	152	246	244	63.655 Total χ^2 (d.f. 46) 26.954** Pooled χ^2 (d.f. 2) 36.701 Interaction χ^2 (d.f. 44)
Bigeye	1-15	1	6	8	5.200
	16-20	4	6	5	0.400
	21-31	1	12	13	10.227**
	Total	6	24	26	15.827* Total χ^2 (d.f. 6) 12.997** Pooled χ^2 (d.f. 2) 2.829 Interaction χ^2 (d.f. 4)

1/ Stations combined to give minimum expected catches of 5.
* Significant at the 0.05 level.
** Significant at the 0.01 level.

To further elucidate the depth distribution of tunas, some gear with 30-fathom float lines and some with 2-fathom float lines was fished along with the regular gear having 10-fathom float lines (table 17). There was little difference in the yellowfin catch among the three types of gear, however, during this cruise there was also no significant difference in the catch of yellowfin with relative depth within the regular gear. On the other hand, during each experiment the deepest fishing gear caught more bigeye (table 17), and during this cruise the bigeye were taken in greater numbers on the deeper hooks of the regular gear (table 13).

Table 15.--Yellowfin, bigeye, and albacore tuna catch by relative hook depth, Manning cruise 13

Species	Station[1/]	Shallow	Intermediate	Deep	χ^2
Yellowfin	1-9	8	5	2	3.600
	10-11	6	11	11	1.792
	12-14	7	8	10	0.560
	15-17	5	7	4	0.876
	18-20	7	6	11	1.750
	21-24	4	7	13	5.250
	25-28	3	8	5	2.376
	Total	40	52	56	16.204 Total χ^2 (d.f. 14) 2.811 Pooled χ^2 (d.f. 2) 13.393 Interaction χ^2 (d.f. 12)
Bigeye	1-28	7	5	15	6.222*
Albacore	1-28	0	6	16	17.826**

1/ Stations combined to give minimum expected catches of 5.
* Significant at the 0.05 level.
** Significant at the 0.01 level.

Table 16.--Analysis of yellowfin and bigeye tuna catch by relative hook depth, Smith cruise 18

Species	Station[1/]	Shallow	Intermediate	Deep	χ^2
Yellowfin	1-18	6	5	7	0.333
	20-22	4	5	6	0.400
	23-37	9	7	10	0.538
	Total	19	17	23	1.271 Total χ^2 (d.f. 6) 0.949 Pooled χ^2 (d.f. 2) 0.322 Interaction χ^2 (d.f. 4)
Bigeye	1-4	5	4	7	0.876
	5-12	2	4	9	5.200
	14-37	9	3	7	2.949
	Total	16	11	23	9.025 Total χ^2 (d.f. 6) 4.359 Pooled χ^2 (d.f. 2) 4.666 Interaction χ^2 (d.f. 4)

1/ Stations combined to give minimum expected catches of 5.

Accumulated data on the relative vertical distribution of yellowfin, bigeye, and albacore (see data in Murphy and Shomura 1953a, b) indicate that yellowfin are usually but not consistently more abundant at the deeper levels in the equatorial Pacific, the best bigeye catches are more regularly associated with the deeper fishing levels, and albacore are clearly caught in greatest abundance on the deepest fishing hooks. This may be a reflection of the general horizontal distribution of these three species. Yellowfin appear to be a tropical species; bigeye are also tropical in occurrence but are abundant considerably farther north than the yellowfin (Nakamura 1949); surface albacore are abundant in northern waters not inhabited by the yellowfin nor the bigeye. It seems probable that temperature is one of the chief controlling factors in the latitudinal distribution of these species, and very likely it is also responsible, at least in part, for a difference in vertical distribution in the equatorial region, with the species whose distribution extends farther north apparently occupying deeper, colder waters in the tropics.

Table 17.--Catches of yellowfin on 10 baskets of special gear compared with the catches of the adjacent 10 baskets of standard gear, Manning cruise 12

Station	Yellowfin		Bigeye	
	Standard	30-fathom float lines 1/	Standard	30-fathom float lines 1/
2	2	1	-	1
4	6	9	-	1
6	1	1	-	1
9	3	5	-	-
11	3	-	-	-
Total	11	16	0	3

Station	Standard	2-fathom float lines 2/	Standard	2-fathom float lines 2/
3	3	-	1	-
5	1	5	1	-
8	1	1	-	-
10	3	-	-	-
12	-	-	-	-
Total	8	6	2	0

1/ Identical with standard gear, except that the 10-fathom float lines were replaced with 30-fathom lines.

2/ Gear made up with 2-fathom float lines and with droppers consisting of a 1-foot cotton section, a 4-fathom sekiyama section, and a fathom of wire leader.

IMPROVEMENT OF LONGLINE GEAR

The first longlines designed by POFI were essentially modifications of the gear used commercially by Hawaiian and Japanese fishermen. One of the components of this gear is the

"sekiyama", a 22-foot section constructed of 12 strands of No. 8 Irish linen whipped with No. 6 cotton located between the cotton line and the wire leader of each dropper. The sekiyama is used to provide a good gripping surface on the part of the line most often handled in fighting fish, and also perhaps to resist abrasion of the line on the hull when fish go under the boat. Because it is one of the more expensive components of the longline gear (about $2.25 each), an experiment was conducted to ascertain whether the 261-thread cotton line used in the balance of the gear could be substituted for it.

On Manning cruise 13, 10 baskets of longline gear in which 261-thread cotton line was substituted for the sekiyama were fished in addition to 40 baskets of standard gear. A comparison of the catch on this gear with the catch of the 10 adjacent baskets of standard gear is given in table 18. The capture of 56 fish on each type of gear is a good indication that the efficiency was not changed by the elimination of the sekiyama. Insofar as durability is concerned, five droppers were broken on each of the two types of gear. During the cruise both scientists and fishermen were in agreement that the absence of the sekiyama did not cause undue difficulty in handling fish.

Table 18.--Analysis of catch of experimental baskets with 10 adjacent standard baskets, Manning cruise 13

Station	With sekiyama	Without sekiyama	Total catch 1/
1-3	5	8	13
4-8	4	8	12
9-11	8	8	16
14, 15	7	5	12
16, 17	6	5	11
18, 19	8	4	12
20, 21	4	9	13
22-24	7	4	11
25-28	7	5	12
Total	56	56	112

1/ Catch includes all species except sharks.

SHARK DAMAGE TO THE CATCH

Varying fractions of the catch were damaged by sharks. This damage usually takes the form of one or more bites from the body of the tuna while it is being hauled in. The problem is of considerable importance to a commercial fishery because severely bitten fish are unsuitable for canning. In considering the data it should be borne in mind that: (1) our records of shark-bitten fish did not include estimates of the severity of the damage to each fish (about one-half of the fish recorded as bitten are probably unsuitable for the cannery); and (2) no particular effort has been made during the course of POFI experimental fishing to reduce shark damage. For these reasons our estimates of the severity of the problem can be considered as maximal.

During the course of six cruises 21 percent of all yellowfin landed were damaged by sharks (table 19). If half of these were unsuitable for canning, the net loss would be about 10 percent of the catch. It is of interest to note that the percent of loss to sharks appears to be related to the size of the fish. For instance, bigeye, the largest species in the catch, sustained the highest rate of shark damage; and skipjack, the smallest species, sustained the lowest rate.

his may in part be related to the relative inconspicuousness of the smaller fish, but more likely related to the speed of handling. Most shark damage occurs at the surface while a hooked fish being hauled in, and small fish like skipjack are landed with considerably more celerity than rge fish such as bigeye. This indicates that shark damage can be considerably lessened by re-cing the "playing time" in bringing fish aboard.

Table 19.--Summary of shark-bitten tuna (by species), Manning cruises 11, 12, and 13, Gilbert cruise 1, Cavalieri cruise 1, Smith cruise 18

Cruise	Yellowfin		Bigeye		Skipjack		Albacore		Total	
	Catch	Percent shark bitten	Catch	Percent shark bitten	Catch	Percent shark bitten	Catch	Percent shark bitten	Catch	Percent shark bitten
Manning 11	211	18.5	30	36.7	17	11.8	64	15.6	322	19.2
Manning 12	146	23.3	28	35.7	9	0.0	2	50.0	185	24.3
Cavalieri 1	720	19.9	65	21.5	29	6.9	-	-	814	19.5
Smith 18	59	15.3	51	27.4	14	0.0	1	0.0	125	18.4
Manning 13	148	29.1	28	17.9	34	14.7	21	23.8	231	25.1
Gilbert 1	72	25.0	43	11.6	1	0.0	-	-	116	19.8
Total	1356	21.1	245	24.1	104	8.7	88	18.2	1793	20.6

SUMMARY

. During the period August to November 1952 there were four longline fishing cruises to the equatorial Pacific between 120°W. and 170°W. longitude.

. Upwelling was very intense at the Equator on 120°W. longitude. Yellowfin catches were low in this upwelled water, suggesting that the water had not been in the photosynthetic zone long enough to have developed a favorable food supply.

. Along 130°W. longitude upwelling was somewhat less intense than on 120°W., and in the zone of upwelled water moderate quantities of yellowfin were taken.

. Two sections along 150°W. longitude and one along 140°W. gave evidence of moderate upwelling. Along these sections there was a marked concentration of yellowfin tuna to the north of the Equator.

. Compared with the results of other cruises, there was only moderately good fishing along 150°W. longitude in August and October, although good fishing was experienced during the intervening month (September). This may be an indication of the magnitude of the short-term fluctuations to be expected in that region.

. Albacore were relatively abundant a few degrees south of the Equator on the western section (169°W. longitude).

. Japanese commercial fishing in the region of 170°W. - 180° longitude showed bigeye relatively abundant north of 5°N. latitude, and yellowfin relatively abundant south of that latitude. Catch rates of the Japanese vessels were almost identical with catch rates of POFI experimental fishing.

8. The size of the longline-caught yellowfin and bigeye increases from west to east. The differences in size are compatible with apparent differences in the amount of upwelling, suggesting that there are fundamental differences in the growth rates of yellowfin and bigeye among the western, central, and eastern Pacific, related to the relative productivity of the three areas.

9. The preponderance of males in longline catches of yellowfin may be a reflection of a higher mortality of females after a certain age.

10. A method of using the echo sounder to ascertain the depth fished by the longline was devised, and preliminary results of its application are given. In most instances considerable streaming of the line prevented it from reaching its maximum possible depth.

11. In general yellowfin catches were higher on the deep and intermediate hooks, and less on the shallow hooks. Bigeye and albacore were taken most frequently on the deep hooks.

12. Experimental fishing indicated that the expensive sekiyama sections of the branch lines can be eliminated.

13. An estimated 10 percent of the catch was unsuitable for delivery to the cannery because of mutilation by sharks. This figure can probably be reduced in commercial operations.

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APPENDIX

Summarized Field Data

Table 20.--Time taken for setting and hauling the longline gear, Manning cruise 12

Station[1]	Set			Haul					Fish handling break[4] (min.)
					Regular gear		Experimental gear[3]		
	Total baskets set	Time started to set	Time taken for setting (min.)	Time started to haul	Number of baskets	Time taken[2] for hauling (min.)	Number of baskets	Time taken for hauling (min.)	
1	40	0633	64	1226	40	201	-	-	68
2	50	0557	73	1200	40	219	10	62	43
3	50	0600	78	1222	40	207	10	65	53
4	50	0600	72	1215	40	176	10	57	25
5	50	0600	75	1208	40	166	10	65	26
6	50	0554	66	1205	40	220	10	44	21
8	50	0605	70	1220	40	252	10	38	51
9	50	0610	70	1222	40	182	10	57	53
10	50	0602	68	1215	40	164	10	41	32
11	50	0610	62	1226	40	175	10	42	35
12	50	0605	75	1212	40	171	10	47	28
15	40	0605	55	1230	40	190	-	-	37
16	40	0608	45	1240	40	177	-	-	33
17	40	0610	52	1228	40	182	-	-	30
18	40	0612	36	1251	40	195	-	-	39
19	40	0605	45	1235	40	138	-	-	21
Average			1.36 min. per basket			4.71 min. per basket	Deep gear 5.24 min. per basket Shallow gear 5.12 min. per basket		

1/ Fishing stations 21 and 22 were special stations for diurnal study and are therefore omitted.
2/ Does not include the fish handling break.
3/ Stations 2, 4, 6, 9, and 11, with deep fishing gear; stations 3, 5, 8, 10, and 12, with shallow fishing gear.
4/ Break came midway during hauling of the regular baskets.

Table 21.--Time taken for setting and hauling the longline gear, Cavalieri cruise 1

Station	Number of baskets	Set		Haul	
		Time started to set	Time taken for setting (min.)	Time started to haul	Time taken for hauling (min.)
1	50	0509	64	1200	395
2	50	0509	61	1159	261
3	60	0508	87	1201	319
4	60	0507	84	1256	297
5	60	0512	86	1149	290
6	61	0505	89	1208	257
7	70	0458	106	1138	378
8	70	0513	94	1155	283
9	70	0453	94	1200	314
10	70	0458	110	1150	304
11	76	0507	114	1213	347
12	70	0500	117	1149	301
13	79	0457	98	1145	375
14	79	0504	105	1150	336
15	60	0457	86	1235	253
16	75	0458	107	1213	319
17	79	0506	115	1231	316
18	80	0504	118	1218	375
19	80	0504	103	1228	347
20	81	0500	110	1219	331
21	80	0459	104	1220	334
22	80	0506	107	1234	332
23	80	0505	109	1213	364
24	80	0428	110	1143	362
25	81	0441	108	1148	370
26	80	0428	121	1226	327
27	85	0427	124	1149	356
28	80	0428	124	1150	550
29	80	0443	116	1155	493
30	80	0437	112	1133	367
31	80	0433	113	1135	327
Average			1.41 min. per basket		4.67 min. per basket

Table 22.--Time taken for setting and hauling the longline gear[1/], Smith cruise 18

Station	Set		Haul		Fish handling break (min.)
	Time started to set	Time taken for setting (min.)	Time started to haul	Time taken for hauling[2/] (min.)	
1	0600	48	1234	274	55
3	0550	48	1211	218	47
4	0547	47	1213	220	44
5	0540	47	1220	192	52
6	0543	47	1214	232	76
7	0541	49	1211	159	76
8	0540	27	1217	195	51
9	0553	43	1219	155	63
10	0539	49	1218	153	57
12	0548	47	1212	172	48
14	0536	47	1210	153	65
16	0619	41	1231	152	42
18	0603	47	1212	150	54
20	0635	47	1212	163	49
22	0537	43	1214	159	54
23	0604	45	1248	155	50
25	0610	44	1255	163	47
27	0611	45	1250	152	48
29	0608	44	1251	153	70
30	0609	45	1247	156	47
31	0607	47	1303	161	40
32	0618	64	1256	157	47
33	0618	47	1247	150	56
35	0621	47	1252	148	51
36	0627	49	1252	146	68
37	0630	50	1301	135	48
Average		1.16 min. per basket		4.25 min. per basket	

1/ 40 baskets of gear used on each station.
2/ Does not include the fish handling break.

Table 23.--Time taken for setting and hauling the longline gear[1/], Manning cruise 13

Station[2/]	Set		Haul			Fish handling break (min.)
	Time started to set	Time taken for setting (min.)	Time started to haul	Time taken for hauling (min.)		
				Regular gear	Experimental gear	
1	0614	48	1007	212	53	45
2	0559	61	1244	156	43	46
3	0600	55	1214	189	54	58
4	0555	53	1215	199	58	15
6	0607	48	1213	168	41	43
7	0600	50	1150	156	44	29
8	0600	49	1205	193	57	40
9	0600	55	1214	143	41	36
10	0600	50	1216	148	50	32
11	0603	47	1155	150	41	37
14	0600	55	1202	127	39	28
15	0558	47	1201	137	37	34
16	0553	43	1216	161	43	27
17	0552	48	1202	133	36	24
18	0558	46	1154	142	45	22
19	0602	50	1215	235	66	37
20	0605	50	1200	214	71	22
21	0602	56	1150	150	61	35
22	0557	48	1149	190	39	29
23	0606	52	1157	178	44	30
24	0605	50	1153	169	45	39
25	0604	56	1205	203	43	21
26	0600	55	1212	180	44	24
27	0600	59	1219	156	57	20
28	0605	55	1207	172	43	25
Average		1.03 min. per basket		4.26 min. per basket	4.78 min. per basket	

1/ 50 baskets of gear set at each station--40 regular and 10 experimental.
2/ Stations 12 and 13 were special stations for diurnal study and are therefore omitted.

Table 24.--Complete catch records Manning cruise 12 (40 baskets - 240 hooks)

Station	Yellowfin	Bigeye	Skipjack	Albacore	Marlin	Dolphin	Sharks			Others
							White-tipped	Silky	Great blue	
1	5	-	-	-	4	-	3	-	2	12 1/
2	14	2	-	-	1	-	2	-	-	1 2/
3	11	2	-	-	1	-	-	-	1	-
4	14	3	-	-	-	-	4	-	-	3 3/
5	2	1	1	-	-	-	2	-	-	1 2/
6	8	-	-	-	1	1	1	-	-	2 2/
8	5	2	-	-	1	-	2	-	-	-
9	23	-	-	-	-	-	2	-	1	1 2/
10	9	-	-	-	-	-	4	-	1	-
11	8	-	1	1	1	-	4	-	1	-
12	1	-	1	-	-	-	6	-	-	3 4/
15	3	4	1	1	-	-	6	1	-	3 5/
16	1	1	1	-	-	-	2	-	-	1 2/
17	2	4	-	-	-	-	2	-	-	-
18	2	2	1	-	1	-	2	-	5	-
19	-	-	-	-	-	-	4	1	1	-

1/ 2 unidentified sharks, 8 thresher sharks, 2 lancet fish
2/ unidentified sharks
3/ 2 unidentified sharks, 1 wahoo
4/ 2 wahoo, 1 lancet fish
5/ 3 wahoo

Table 25.--Complete catch records Manning cruise 12, special baskets (10 baskets - 60 hooks). Stations 2, 4, 6, 9, and 11 with 30 f. instead of 10 f. float lines; balance with 2 f. float lines

Station	Yellowfin	Bigeye	Skipjack	Albacore	Marlin	Dolphin	Sharks			Others
							White-tipped	Silky	Great blue	
2	1	1	-	-	-	-	-	-	-	1 1/
3	-	-	-	-	-	-	1	-	-	-
4	9	1	-	-	-	-	-	-	-	-
5	5	-	-	-	-	-	-	-	-	1 2/
6	1	1	-	-	-	-	-	-	1	1 3/
8	-	-	-	-	-	-	1	-	-	-
9	5	-	-	-	-	-	1	-	-	1 2/
10	-	-	-	-	-	-	3	-	-	-
11	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-

1/ wahoo
2/ unidentified shark
3/ lancet fish

Table 26.--Complete catch records of special stations, Manning cruise 12 (10 baskets per group - 60 hooks)

Station	Group	Yellowfin	Bigeye	Skipjack	Albacore	Marlin	Dolphin	Sharks			Others
								White-tipped	Silky	Great blue	
21[1/]	I	1	-	-	-	-	-	-	-	-	-
2°01'N,	II	2	-	-	-	-	-	1	-	-	1[3/]
141°21'W	III	2	-	1	-	-	-	-	-	-	-
	IV	-	1	-	-	-	-	-	1	-	-
	V	-	3	-	-	1	-	-	-	-	1[3/]
	VI	-	-	-	-	-	-	1	-	-	-
22[2/]	I	1	-	-	-	-	-	-	1	-	-
1°56'N,	II	1	-	1	-	-	-	1	-	-	-
142°23'W	III	2	-	-	-	-	-	1	-	-	-
	IV	6	-	-	-	-	-	3	1	-	-

1/ Group I set 0618, hauled 0912; group II set 0955, hauled 1253; group III set 1337, hauled 1703; group IV set 1756, hauled 1809; group V set 2142, hauled 2200; group VI set 0206, hauled 0512.

2/ All four groups set consecutively starting at 0606, hauling times: group I - 0903, group II - 1042, group III - 1500, group IV - 1726.

3/ Unidentified shark

Table 27.--Complete catch records, Cavalieri cruise

Station	Hooks	Yellowfin	Bigeye	Skipjack	Albacore	Marlin	Dolphin	Sharks			Others[1/]
								White-tipped	Silky	Great blue	
1	300	2	1	-	-	2	1	-	-	-	2
2	300	4	1	-	-	2	-	2	-	2	8
3	360	15	4	-	-	-	-	1	-	-	8[2/]
4	360	18	-	4	-	-	1	-	-	-	3
5	360	34	7	2	-	-	-	2	-	-	7[3/]
6	366	32	-	-	-	-	-	1	-	-	4
7	414	49	-	1	-	-	-	4	-	2	8[4/]
8	420	12	-	1	-	1	-	-	-	2	5[2/]
9	420	24	-	1	-	-	-	2	-	3	2[5/]
10	420	25	1	1	-	1	-	3	-	2	2
11	456	34	-	-	-	1	-	2	-	8	3[5/]
12	420	13	-	1	-	-	-	3	-	1	2
13	474	19	-	4	-	-	-	-	-	2	3
14	474	8	-	-	-	-	-	2	-	8	6[6/]
15	360	12	1	-	-	-	-	-	-	2	1[7/]
16	450	21	4	2	-	-	1	-	-	-	-
17	474	23	3	1	-	-	-	3	-	1	2
18	480	17	3	-	-	1	-	2	-	2	2[8/]
19	480	23	4	-	-	-	-	1	1	1	3[2/]
20	480	21	1	-	-	-	-	1	1	2	4[5/]
21	480	15	1	5	-	-	-	1	-	-	1
22	480	20	-	-	-	1	-	2	-	2	2[9/]
23	480	9	4	-	-	1	-	6	-	2	3[3/]
24	480	27	4	1	-	2	-	6	-	-	2
25	486	27	2	2	-	-	-	7	-	-	2[7/]
26	480	24	2	-	-	2	-	-	1	-	2[10/]
27	510	15	2	-	-	2	-	-	-	-	2[5/]
28	480	33	3	-	-	1	-	-	-	-	2[5/]
29	480	61	6	3	-	1	-	5	-	-	4[3/]
30	480	43	6	-	-	-	-	-	-	-	4
31	480	38	5	-	-	-	-	9	-	-	3[11/]

1/ "Others" are all unidentified sharks except as otherwise noted.
2/ 1 wahoo
3/ 1 broadbill swordfish
4/ 1 thresher shark, 1 lancet fish
5/ 1 lancet fish
6/ 2 lancet fish
7/ 1 hammerhead shark
8/ 1 thresher shark
9/ 1 thresher shark, 1 wahoo
10/ 1 bonito shark
11/ 2 bonito sharks

Table 28.--Complete catch records of special stations, Manning cruise 13 (10 baskets per group - 60 hooks)

Station	Group	Yellowfin	Bigeye	Skipjack	Albacore	Marlin	Dolphin	Sharks			Others
								White-tipped	Silky	Great blue	
12[1]	I	-	-	-	-	-	-	-	-	-	-
2°15'N,	II	4	-	1	-	-	-	7	-	-	-
151°16'W	III	2	-	-	-	-	-	5	-	-	-
	IV	-	-	-	-	-	-	9	-	-	-
	V	-	-	-	-	-	-	11	1	-	1[3]
	VI	-	-	-	-	-	-	3	-	-	-
13[2]	I	-	-	1	-	-	-	-	1	-	-
2°07'N,	II	2	-	2	-	-	-	-	-	-	-
151°37'W	III	2	-	-	-	-	-	1	-	-	-
	IV	3	-	1	-	-	-	1	-	-	-

1/ Group I set 0555, hauled 0901; group II set 0935, hauled 1306; group III set 1401, hauled 1703; group IV set 1738, hauled 2106; group V set 2153, hauled 0102; group VI set 0155, hauled 0505.

2/ All four groups set consecutively starting at 0555. Hauling times: group I - 0900, group II - 1157, group III - 1518, group IV - 1754.

3/ Broadbill swordfish

Table 29.--Complete catch records, Manning cruise 13 (40 regular baskets - 240 hooks)

Station	Yellowfin	Bigeye	Skipjack	Albacore	Marlin	Dolphin	Sharks			Others
							White-tipped	Silky	Great blue	
1	-	-	-	4	-	2	-	-	-	2[1]
2	-	2	-	-	-	2	1	-	1	3[2]
3	-	4	1	-	1	-	1	-	-	2[1]
4	-	1	1	-	-	-	1	-	1	5[3]
6	-	4	-	-	-	-	2	1	1	-
7	2	1	-	-	2	-	4	1	3	-
8	5	-	-	-	1	-	1	1	-	1[1]
9	4	1	-	-	2	-	3	-	-	1[1]
10	6	3	-	-	-	-	8	1	-	2[1]
11	18	-	2	-	2	-	11	-	-	-
14	9	1	1	-	1	-	4	-	1	-
15	3	-	9	-	-	-	9	-	-	2[4]
16	8	-	-	-	-	-	8	-	-	-
17	2	-	-	-	1	-	2	1	2	1[5]
18	4	-	-	1	-	-	7	-	-	2[1]
19	7	2	-	7	-	-	-	-	1	-
20	5	-	-	3	-	-	1	-	3	-
21	4	-	1	-	1	-	3	-	-	1[6]
22	2	1	2	2	1	-	2	-	-	-
23	3	-	1	-	-	-	2	-	-	-
24	9	-	1	-	-	-	1	1	2	1[7]
25	8	-	3	-	-	-	-	1	1	-
26	3	-	-	-	-	-	-	1	-	-
27	1	-	1	-	1	-	2	5	1	1[1]
28	3	-	-	-	-	-	1	1	-	1[8]

1/ lancet fish

2/ 2 lancet fish, unidentified shark

3/ 4 lancet fish, 1 unidentified shark

4/ 1 lancet fish, 1 sunfish

5/ wahoo

6/ shortnosed spearfish

7/ unidentified shark

8/ sunfish

Table 30. --Complete catch records, Manning cruise 13
(10 baskets without sekiyama - 60 hooks)

Station	Yellowfin	Bigeye	Skipjack	Albacore	Marlin	Dolphin	Sharks			Others
							White-tipped	Silky	Great blue	
1	-	-	-	2	-	-	-	-	-	1 1/
2	-	2	-	-	-	-	-	-	-	-
3	-	3	-	-	-	-	-	-	-	1 1/
4	-	-	-	-	-	-	1	-	2	-
6	-	-	-	-	1	-	-	-	-	1 2/
7	1	-	-	-	1	-	1	-	-	-
8	3	1	-	-	-	-	2	1	-	-
9	-	2	-	-	1	-	2	-	-	-
10	1	-	-	-	-	-	2	-	-	-
11	3	-	-	-	1	-	1	-	-	-
14	3	-	1	-	-	-	-	-	-	-
15	-	-	1	-	-	-	4	1	-	-
16	1	-	-	-	1	-	1	-	-	1 3/
17	2	-	-	-	-	-	1	-	-	-
18	1	-	-	-	-	-	3	-	-	-
19	2	-	-	1	-	-	-	-	-	-
20	5	-	-	1	-	-	-	-	-	-
21	3	-	-	-	-	-	-	-	1	-
22	-	-	-	-	-	-	-	-	-	-
23	1	-	1	-	-	-	-	-	-	-
24	2	-	-	-	-	-	-	-	-	-
25	1	-	2	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	1	-	1	1	-	-
28	-	-	-	-	-	-	1	-	-	-

1/ lancet fish
2/ sailfish
3/ sunfish

Table 31.--Complete catch records, Smith cruise 18
(40 baskets - 240 hooks)

Station	Yellowfin	Bigeye	Skipjack	Albacore	Marlin	Dolphin	Sharks			Others
							White-tipped	Silky	Great blue	
1	-	-	-	-	-	-	6	-	-	-
3	5	5	-	-	2	-	-	-	-	8 1/ 2/
4	1	11	-	-	-	-	6	-	1	3 1/
5	-	1	-	-	1	-	-	-	-	8 3/
6	-	3	-	-	-	3	3	1	1	13 1/
7	-	1	-	-	1	-	2	11	6	7
8	-	8	-	-	-	-	3	1	3	-
9	1	-	-	-	-	-	1	-	-	1 1/
10	-	-	-	-	2	-	1	-	5	-
12	3	2	-	-	-	-	1	-	1	1 4/
14	-	1	-	-	3	-	6	-	1	1 5/
16	4	1	-	-	1	-	4	-	2	-
18	4	1	3	1	-	-	2	-	-	-
20	14	3	-	-	-	-	-	-	-	-
22	1	1	-	-	-	-	-	-	-	1 1/
23	3	2	1	-	-	-	5	-	1	1 5/
25	6	3	5	-	1	-	5	1	-	1 5/
27	2	-	-	-	-	-	6	-	1	-
29	5	-	-	-	-	-	5	-	1	-
30	-	2	-	-	1	-	6	-	12	-
31	3	-	-	-	1	-	9	-	6	-
32	1	-	-	-	4	-	4	-	4	2 6/ 2/
33	4	-	-	-	-	-	2	3	4	1
35	1	2	-	-	2	-	3	7	6	-
36	1	3	5	-	-	-	3	2	3	3 7/
37	-	-	-	-	2	1	-	2	1	1 8/

1/ unidentified sharks
2/ lancet fish
3/ 11 unidentified sharks, 2 lancet fish
4/ hammerhead shark
5/ wahoo
6/ lancet fish, bonito shark
7/ lancet fish, wahoo, sailfish
8/ sailfish

Table 32.--Wind direction and force on stations during Manning cruises 12 and 13, Smith cruise 18, and Cavalieri cruise

Station	Manning 12		Manning 13		Smith 18		Cavalieri	
	Prevailing wind	Beaufort force	Prevailing wind	Beaufort force	Prevailing wind	Beaufort force	Prevailing wind	Beaufort force
1	SE	3	W	2	E	3	SE	4
2	SE	3	NE	4			ESE	5
3	E	2	NE	5	SSE	3	ESE	4
4	ESE	5	E	6	S	4	ESE	5
5	SE	4	Night-light 1/		SSE	3	SE	3
6	ESE	3	ESE	3	SSE	4	ESE	4
7	Night-light 1/		SE	4	SSE	4	E	4
8	SE	4	SE	4	S	4	E	3
9	SE	3	ESE	4	SSE	4	E	3
10	E	3	SE	4	ESE	4	ESE	3
11	ENE	3	SE	4			ESE	3
12	ENE	4	SE	5	ESE	4	E	3
13	Night-light 1/		ESE	3			ESE	3
14	Night-light 1/		SE	4	E	4	SE	3
15	SE	5	ESE	4			ESE	3
16	E	4	ESE	3	E	4	ESE	3
17	ESE	4	NE	3			E	2
18	E	2	NE	4	E	4	E	2
19	SE	3	NNE	4			SE	2
20	Night-light 1/		NNE	2	E	4	SE	2
21	ESE	3	SE	4			SE	2
22	SE	3	E	4	E	4	SE	2
23			ENE	5	ENE	4	SE	2
24			E	5			SE	3
25			ESE	5	ENE	4	SE	2
26			E	6			SE	2
27			E	5	E	4	SE	3
28			E	5			SE	3
29					E	4	SE	3
30					SE	4	SE	3
31					SE	2	SE	3
32					SE	3		
33					SE	4		
34								
35					S	4		
36					S	4		
37					S	4		

1/ Night-light collecting stations, no tuna fishing done.

REPORT OF AN INVESTIGATION OF THE SPEARFISHES OF FORMOSAN WATERS

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United States Department of the Interior, Douglas McKay, Secretary

Fish and Wildlife Service, John L. Farley, Director

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By

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REPORT OF AN INVESTIGATION OF THE SPEARFISHES OF FORMOSAN WATERS

By

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Introduction

This study of the spearfishes has been made as a part of an investigation of the important es of Taiwan. The study was begun in 1934 and thereafter specimens from catches landed at Keelung, Suō, Shinkō, and Takao fish markets were studied, the anatomical work being done nly on material obtained at Suō and on the catch of the research vessel Shonan Maru belonging is laboratory.

The spearfishes (local name旗魚) are the most important element in the Formosan fish h, the production in recent years being as shown in the table below (based on Taiwan fishery istics). The value of these fishes is second only to that of the cultivated milkfish and occupies first place among the catches of all fisheries.

Table 1.--Spearfish catch in six recent years

Year	Quantity	Value
	kin[1/]	yen
1935	7,066,111	1,361,706
1934	7,437,667	1,391,879
1933	5,362,462	1,024,685
1932	5,421,945	914,243
1931	6,545,973	1,025,223
1930	5,485,886	1,210,337

[1/] 1 kin = 1.32 lb.

During the course of an earlier study on the sharks of Formosa the author had opportuni- to observe the handling of spearfishes in the fish markets frequently, because the fishing ions for sharks and spearfishes coincide.

The spearfishes are classified into a number of kinds by the commercial operators and e varieties are handled separately, there being marked differences in their value. At first as extremely difficult to distinguish these varieties, but in the course of many repeated rvations the classification method of the commercial operators gradually became clear and author became able to distinguish the peculiarities of each variety and arrived at the opinion the classification made by the commercial people should be studied from the point of view ystematics.

During the course of this study I have been constantly guided by Professor Hirasaka of Taihoku Imperial University, and for the illustrations I am indebted to Mr. Sakuma of the versity. I also wish to express my thanks to all the persons in the fishing industry throughout island who have shown great understanding and who have facilitated this study in many ways, particularly to the Suō Suisan Kaisha.

I. Species

A. General

Among the systematic studies and publications concerning the spearfishes of Japan, D. S. Jordan and J. O. Snyder [1] have recorded two species. These are Tetrapturus mitsu the makajiki, and T. mazara. Dr. Tanaka [2] had earlier recorded the following five specie from Japan:

Family Istiophoridae, genus Istiophorus

1. Istiophorus orientalis

Genus Tetrapturus

2. Tetrapturus mitsukurii
3. Tetrapturus mazara
4. Tetrapturus angustirostris

Family Xiphiidae, genus Xiphias

5. Xiphias gladius

In recent years the same author has reported the following two species as represent of the genus Tetrapturus. These are T. mitsukurii [3] and T. angustirostris [4], and he gives following explanation with regard to them. "Species close to this one (the striped marlin) ar called black marlin and white marlin at Tokyo, but it is not clear whether these are separat species or varieties within a single species." Accordingly the new species T. mazara recor by Jordan and Snyder is in recent writings of Dr. Tanaka treated as the same species or a variety of the same species as T. mitsukurii. And although he does not clearly call for the suppression of T. mazara, in actuality it amounts to its complete suppression.

The writer knows nothing of the fish called black marlin and white marlin at Tokyo, b the fish called black marlin (or black-skinned marlin) and white marlin (or white-skinned ma at Formosa are of course different from the striped marlin and these two species certainly a not identical. If it is supposed that the commercial operators at Tokyo apply these several n to the several species in the same way that they are used in Formosa, the quotation above ci from Dr. Tanaka should not be "black marlin or white marlin" but "black marlin and white marlin" and instead of speaking of "both of these species" he should speak of "these three species."

D. S. Jordan and B. W. Evermann [5] have divided the spearfishes of the whole world two families and four genera and record 32 species, 20 of them for the Indo-Pacific region. F. Day [6] [7] has reported three species, Histiophorus gladius, H. immaculatus, and H. brevirostris from the Indian Ocean. From South Africa K. H. Barnard [8] has reported H. gladius and Makaira herscheli.

1/ Jordan and Snyder. 1901, Jour. Coll. Sci. Imp. Univ., Tokyo.
2/ Tanaka, Shigeo. Japanese Ichthyology, Volume 1, 1921.
3/ Tanaka, Shigeo. Illustrated atlas of useful, harmful, and admirable aquatic animals plants, 1933.
4/ Tanaka, Shigeo. Fishes of Japan, Vol. 1, 2nd edition, p. 324, 1935.
5/ Jordan and Evermann: Occ. Papers Calif. Acad. Sci. XII, 1926.
6/ Day F. Fishes Ind., Vol. 1, pp. 198-199, 1878.
7/ Day, F. Fauna Brit. Ind., Fish, Vol. 2, 1889.
8/ Barnard, K. H. Ann. South Africa Mus., Vol. 21, Part 2, 1925-1927.

Of these species M. herscheli from South Africa is, according to Lütken[9/], the same
s as T. brevirostris of the Indian Ocean, and according to K. H. Barnard H. gladius is
nym of H. indicus.

The lack of agreement and state of complete confusion among the opinions of the various
s may be thought to be due perhaps to the fact that these fish are very large, handling and
of them is inconvenient, and the preservation of type specimens is difficult. It is thought
nother important cause is that in many cases the specimens used in the studies were
plete. In many cases the commercial fishermen customarily cut off and throw away the
hout, which is without any practical value. For example, it appears that the two species
led by Jordan and Snyder from Japan were based on studies made of incomplete specimens
aki in Kanagawa Prefecture.

The spearfishes taken in Formosa are distinguished by the commercial operators as
s:

1. red spearfish - akakajiki or aka /striped marlin/*
2. black marlin - kurokajiki or kurokawa kajiki
3. white marlin - shirokajiki or shirokawa kajiki
4. sailfish - baren or bashōkajiki
5. a species with no definite name (furaikajiki) /the shortnosed spearfish/
6. broadbill - tsun or mekajiki

Among these, species 1 to 5 belong to the family Istiophoridae, 6 belongs to the family
dae. The sailfish, shortnosed spearfish, and broadbill, because of their peculiar form,
asily distinguished from the other three, and are also easily differentiated from one another.
roblem is in whether species 1 to 3 are, as Dr. Tanaka has said, actually one species or
pecies or whether the three should all be treated as separate species.

According to Jordan and Evermann, the genus Istiophorus includes four species from the
Pacific region, with perhaps a still different species from Formosa, but the sailfish of
osa is the same species as that of Japan proper and no other species is known up to the
nt.

The red marlin /striped marlin/, black marlin, and white marlin also have clear morpho-
l characteristics and can easily be distinguished by a slightly practiced eye, the differentia-
eing extremely easy even in the case of specimens which have had their heads and tails
f.

B. Morphological Comparison

As has been stated, the spearfishes have conspicuous external characters which make it
for an experienced eye to distinguish between them at a glance, but it was thought that
hologically, rather than such external elements as coloring and markings, internal elements
as differences in skeleton and musculature are more important and fundamental. Accord-
it is believed that external morphological differences should be corroborated by comparisons
eleton and musculature, and at the same time it is thought that a considerable contribution
conomy may result from these comparisons.

With the object of eliminating, insofar as possible, observational errors due to individual
iarities, the author wished to inspect and dissect as many specimens as possible, however,
s difficult to tell how many specimens would be sufficient, and, except in particular cases,
ndividual peculiarities are not striking enough to require consideration; consequently dis-
ons have been performed upon only the following numbers of specimens.

9/ Jordan and Snyder. Jour. Coll. Sci. Imp. Univ., Tokyo, 1901.

* Translator's note: Akakajiki, literally "red spearfish", is evidently the name applied in
ormosan fishery to the striped marlin, which is called in Japan makajiki, literally "true
rfish."

Species	Number	Female	Male	Sex undetermined
Striped marlin	16	7	9	-
Black marlin	5	3	2	-
White marlin	5	2	3	-
Sailfish	3	-	-	3
Shortnosed spearfish	11	6	5	-
Broadbill	3	-	-	3

As a result of the observation of the above specimens it appears that the greatest am of individual variation is found in the shape of the cranium, so that it would be difficult to re nize any basic form for it. In the case of the vertebrae and the so-called membrane bones, although there was more or less individual variation, the basic forms were comparatively cl and they were convenient for carrying out comparisons among the species.

I. External form

(a) General appearance

The most conspicuous characteristic of the spearfishes is a sword or spearshaped up jaw formed by the prolongation of the premaxillary, maxillary, and nasal bones. The princi bones making up the elongated upper jaw are the premaxillary and the nasals, the maxillary itself attaining only one-half the length of the upper jaw as a whole.

In the broadbill swordfish the snout is conspicuously flattened and broad, having the s of a double-edged sword, but in the Istiophoridae it has the form of an elongated cone with a roughly circular cross section. The note of Jordan and Evermann[10/] in regard to this point, "upper jaw prolonged into a spear or sword which is shorter and narrower and more flattened on the edge than in the true swordfish or broadbill" can hardly be thought to be based on comp observations.

Generally the bodies of the spearfishes other than the broadbill are markedly longer a at the same time more laterally compressed than those of the scombroid fishes, which are co sidered to be most closely related to them. In the Istiophoridae generally, in differing degre the outline of the dorsal surface projects conspicuously anterior to the origin of the first dors fin, with a gradual slope posteriorly from this part to the caudal peduncle. The ventral profi is somewhat swelled out in the vicinity of the base of the ventrals but to a far less conspicuou degree than in the case of the dorsal projection.

The greatest body depth is measured between the origin of the ventrals and between th third spine and the second soft ray of the first dorsal, the line passing just through the poste end of the base of the pectoral fins. If the head is cut off on this line, the rest of the body fo an almost regular trapezoid, although the bases of the second anal and the second dorsal proj somewhat. The trunk is more or less compressed laterally and the caudal portion is roughl round, the cross section through the caudal peduncle being circular. The degree of lateral c pression is most striking in the shortnosed spearfish, followed by the sailfish, and is least c spicuous in the black marlin. In the broadbill, except for the snout, the body of the fish is a well proportioned spindle shape, the trunk is short, and the projection on the dorsal profile i far less conspicuous than in the case of the istiophorids. The istiophorids have two pairs of keels on the caudal peduncle, while the broadbill has a single pair of very large ones.

Among the istiophorid fishes the body depth is greatest in the white marlin and least i the shortnosed spearfish, there being quite striking differences among the species in the

10/ Jordan and Evermann. Occ. Papers, Calif. Acad. Sci., XII, 1926.

n of body length* to body depth, these proportions being 4.460 for the white marlin, the black marlin, 5.231 for the striped marlin, 6.371 for the sailfish, and 6.881 for nosed spearfish. However, the body depth used here was measured along the curved f the side of the body, so in actuality the ratio between body length and body depth should . Experiments on several fish of each species showed that, although there are differ- ong the species, the ichthyological body depth is 83 to 86 percent of the body depth l over the curved surface of the side. Because the fishes are so large, it was impossible re the body depth as ordinarily used by ichthyologists, and as there is considerable t error in converting the measured values to the ichthyological body depth in accordance above mentioned experimental measurements, it was decided to use the body depth as d over the curved surface of the side.

he black marlin differs from the other fishes of the genus Tetrapturus in that the body spicuously toward a cylindrical form, and the body depth at the origin of the first anal eater than in the other species, being only slightly less than the greatest body depth. depth at the origin of the first anal fin is greatest in the black marlin and smallest in nosed spearfish, the ratios between the body length and body depth at this part in the ies being 5.682 for the black marlin and 7.900 for the shortnosed spearfish (plate 1).

he size of the fish differs among the species, the white marlin attaining the most proportions. The largest fish of this species encountered by the author during his ation measured 2,713 millimeters from the posterior edge of the eye to the caudal . From the author's data and from the reports of experienced commercial operators s that the order of size of these fishes of the family Istiophoridae is white marlin, arlin, striped marlin, sailfish, and shortnosed spearfish. It is said that there are very oadbill swordfish, but at Taiwan no specimen greater than 1,500 millimeters in body ithout the sword has been seen (plate 2).

Coloration and markings

In the broadbill the dorsal surface is a deep blackish brown, with a bluish tint in the fresh n, and the belly is yellowish white. The blackish brown color of the back becomes grad- hter along the sides and the boundary between it and the belly color is indistinct. All of are dark blackish brown and there are no markings or spots anywhere on the body nor elly or the opercles have any shining silvery coloration.

In the fishes of the family Istiophoridae in general the dorsal surfaces are dark purple indigo tint and the bellies are shining silver. The boundary line between these two ons is comparatively clear and forms a finely serrated straight line paralleling the dorsal rather than running along the exact center of the sides of the body. When the fish are d the slime has not yet dried, all of the fins except the first dorsal and the first anal are blue-black color. In specimens which have been exposed to the air for a long time the the fins changes to a blackish brown. When dried, the first dorsal and the anal fins are eep blue-black, but when they are fresh these two fins are a bright cobalt blue. In spe- which have already been exposed to the air for a long period of time and in which the ng portions of the first dorsal and anal fins have changed to a deep blue-black color, if ered portions of the fins are taken out and examined it is found that the covered moist s are bright cobalt blue and thus it may appear that those portions have a particular mark- wever, this color /difference/ is not a marking which appeared on these fins in life.

The black marlin is so called because the silvery white portion of the belly is covered with slime having a purplish tint and the coloration of the whole body is conspicuously tinged own. In white marlin which are fresh and from which the slime has not yet been removed

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ranslator's note: According to a personal communication from the author, the "body , where not otherwise defined, is the total length from the "tip of the snout to the caudal le."

A - black marlin

B - striped marlin

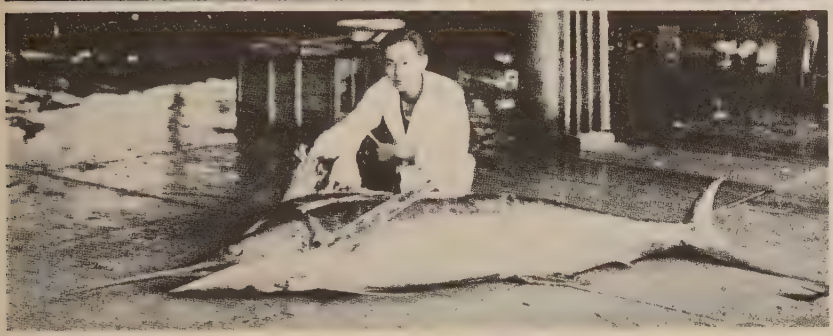
C - sailfish

D - shortnosed spearfish

E - white marlin

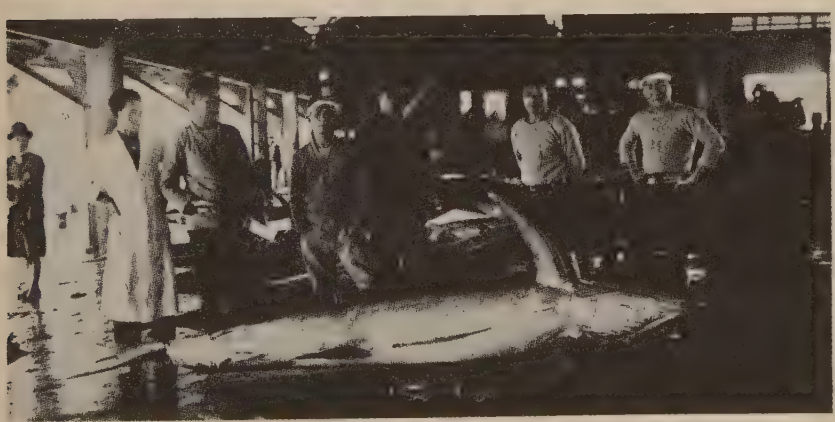
Plate 1.--Cross sections of spearfish (cut at the tip of the pectoral fins).

A



B

C



D

Plate 2.--Three species of the genus Makaira. A - white marlin; B - black marlin; C - striped marlin; D - a gigantic white marlin.

Table 2.--Proportions of various parts of the fish

Species	Body length-head length	Body length-body depth$_1$	Body length-body depth$_2$	Body length-snout length	Head length-snout length	Snout length-head length^1	Head length^1-eye diameter	Upper jaw-lower jaw	Head length-intereye space	Intereye space-eye diameter	E -- D eye diameter	Body depth$_1$-caud.ped. depth	Body depth$_1$-pect. fin	Body depth$_1$-I. D.
Black marlin (24)	2.758	4.561	5.682	2.965	1.525	2.546	4.132	2.211	5.696	2.514	4.215	5.905	1.199	1.535
White marlin (36)	2.771	4.460	5.845	3.136	1.523	2.291	4.830	1.946	5.750	3.034	4.333	6.124	1.142	1.613
Striped marlin (34)	2.613	5.231	6.911	2.804	1.496	2.449	4.138	1.846	6.123	2.373	4.091	4.910	0.947	1.053
Sailfish (8)	3.188	6.301	7.819	2.828	1.403	3.058	3.725	2.197	7.661	2.353	3.793	4.653	0.899	0.797
Shortnosed spearfish (12)	3.868	6.881	7.900	6.278	--	1.386	3.333	1.281	--	--	--	3.806	6.859	--
Broadbill (6)	1.846	5.187	5.923	1.399	1.328	3.771	3.672	3.787	8.688	1.967	3.370	7.382	1.319	1.071

Body depth$_2^1$ is the greatest body depth.
Body depth$_1$ is the body depth at the origin of the 1st anal fin.
Head length^1 is the length of the head excluding the portion anterior to the posterior edge of the eye.
Numbers in parentheses under species names are the numbers of fish measured.
E -- D Distance from eye to 1st dorsal fin.
I. D. Height of 1st dorsal fin.

sal surfaces are of a pale blue color with a milky tint and the impression given by the ion as a whole is that of pale blue or gray blue, the name being due to the fact that the ion is conspicuously paler than in any of the other species. In the sailfish the deep blue- portion of the back is broad in extent, while in the shortnosed spearfish the belly is a ilvery white and the dorsal surface is the color of steel.

In the white marlin and the shortnosed spearfish there are no spots or markings of any any part of the body, but in the black marlin, sailfish, and striped marlin there are or more transverse bands of bright cobalt blue or a cobalt with a whitish tinge. These erse bands do not extend clear across the dorsal and ventral surfaces but are present only middle of the sides. If the fish is left exposed to the air for a long time these markings lly fade or completely disappear, but if water is poured on the fish and the sides are lightly the markings will again appear clearly. The markings on the black marlin are much less cuous than in the other species. On the first dorsal of the sailfish there are a large number blue-black spots scattered irregularly.

) Head

On the head portion of the spearfishes the elongated jaws are the most marked teristic.

The upper jaw of the broadbill is very long, broad, and flattened, so that in cross section elongated ellipse. The length of the upper jaw measured from the posterior edge of the xillary exceeds 0.7 of the length of the body without the snout.

In the fishes of the family Istiophoridae the upper jaw forms a long slender cone, the of which does not attain 2/5 of the length of the body without the snout. The length of the jaw is greatest in the striped marlin and least in the shortnosed spearfish, the proportions th of the snout to the rest of the body in these two species being 2.804 and 6.278 tively.

Marked differences can be detected among the species in the ratio between the lengths of per and lower jaws. In the broadbill swordfish the ratio is 4-1/4, while among the fishes family Istiophoridae it varies from 1.281 to 2.211, the shortnosed spearfish having the st ratio and the black marlin the largest.

The eminence extending forward from the origin of the first dorsal is not very conspicuous broadbill swordfish, but it is generally noticeable in the fishes of the family Istiophoridae, most marked in the case of the white marlin and least developed in the shortnosed spear- This characteristic of the white marlin is shown by the fact that it is sometimes called nari" or "square shoulders."

The branchiostegal membranes or membrana branchiostega in the istiophorids are long e left and right sides are joined, however, this fusion does not appear in the broadbill. ngth of the branchiostegal membranes varies among the istiophorid fishes, being shortest black marlin, the gills of which can be seen between the branchiostegal membrane and the al girdle. Consequently, differences in the length and form of the branchiostegal rays can e seen.

) /sic/ Scales and lateral line

The broadbill swordfish has no scales and the surface of the body is smooth to the touch. he ventral surface in the pectoral region is rough with somewhat the feel of shark skin. ateral line is not developed in the broadbill.

In the istiophorid fishes the scales are buried in the epidermis. They cover the whole but on the head they are to be seen only around the eyes and on the preopercle. The scales ery hard and strong and are elongated, the tips being pointed or forked, however, the scales

of the head have the form of a long ellipse. The lateral line is well developed and is curved upward conspicuously over the pectoral fins, posterior to which it runs in an approximately straight line along the center of the sides of the body.

(f) Fins

All of the fins except the ventrals are well developed in most families. The ventrals not developed at all in the broadbill, and in the istiophorids they are represented by 1 to 3 th rays. However, none of the fishes occurring around this island have ventrals composed of o one ray.

The first dorsal fin commences anterior to the posterior end of the cranium and the n ber of rays is 40 or more. The most anterior ones are spines, those in the longest portion o the fin are soft rays, their number being about 10, and posterior to these we again find spine In the first dorsal of the broadbill the anterior spines and soft rays are remarkably develope their height exceeding the body depth, but their length decreases rapidly posteriorly, and bey about the 20th ray they are not developed outside of the body. In the Istiophoridae all of the r of the first dorsal fin are developed outside of the body, but the greater part of the fin can be folded away into a sort of sheath which is developed along the dorsal surface.

Jordan and Evermann classified the istiophorids into genera based on the characteristi of the first dorsal fin as follows:

The dorsal fin of the shortnosed spearfish is not very high and its anterior lobe is sm (genus Tetrapturus). In the black marlin, striped marlin, and white marlin of the genus Mak the dorsal fin is low with a high anterior lobe and the anterior spines are thickened. In the sailfish (genus Istiophorus) the dorsal fin is very high and the ventral fins are very long with their rays fused together. Thus the dorsal fins of the Istiophoridae present various conspicuo characteristics.

The pectoral fins are very much developed, their length being only slightly less than t body depth (measured around the side of the body). The pectorals are smallest in the shortno spearfish. A groove in the side of the body into which the pectoral fins fit, such as is seen in the tunas, is not developed in the spearfishes. The structure of the pectoral fins of the white marlin is of a special type which differs from the other spearfishes. In the other fishes of bo the family Istiophoridae and the Xiphiidae the pectoral fins can be pressed tightly against the sides of the body, but it is not possible to do so with the white marlin without breaking the joi between the pectoral girdle and the pectoral fins. For this reason it is very simple for us to find the white marlin among the spearfishes lined up in the fish market, one glance sufficing t show their location. Where a pectoral fin sticks out into the air at right angles from the body among a group of spearfishes, we know that it is a white marlin (see fig. 2).

The ventral fins are most developed in the sailfish and development is poorest in the white marlin, followed by the black marlin. The first anal fin is well developed in both famili In the Istiophoridae there is all along the base a sheath into which the greater part of the fin c be retracted. In the genus Makaira the first anal fin is almost identical in form to the anteri portion of the first dorsal, the first few rays being similarly thickened to a great degree.

The second dorsal and the second anal are well developed in the family Istiophoridae, of them having 6 or 7 rays, but in the broadbill they are poorly developed and each have only 4 rays.

The caudal fin is very well developed in both families. In the broadbill the upper and l lobes are both quite broad and the angle between them is rather small. In fishes of the family Istiophoridae both lobes are narrower than in the broadbill and the angle between them is larg so that they are broadly forked.

leton

Taking a general view of the skeleton, it differs conspicuously from the scombroid which are supposed to be most closely related to these species. The differences between nes of the families Istiophoridae and Xiphiidae are also remarkable, and it must be said is very difficult to compare and describe the skeletons of the fishes of these two families same time. Consequently I shall concentrate here on setting forth the comparisons among nes of the family Istiophoridae and will not touch in any detail upon the broadbill except cial circumstances.

) Cranium

There are no striking differences in the cranium. However, some differences are seen proportion of its length to its breadth. If the crania of these fishes are compared with of the scombroids, striking differences can be seen. Most conspicuous, of course, are differences based on the construction of the snout, which is a peculiarity of these fishes, thin processes on the supraoccipital which are found in the scombroids do not appear in fishes, and the posterior projections of the epiotic and pterotic are conspicuous. In all species there are marked differences among individuals, so that it is difficult to determine sic type (plate 3).

) Vertebrae

The vertebrae of the istiophorid fishes are very characteristic. The vertebrae of the of this family and of the scombroids differ markedly both in form and in number. In the broids the number of vertebrae is fairly great, being from 38 to 50[11]. In the istiophorids genera there are 24 vertebrae and both the neural spines and hemal spines are flattened into plates.

These flat plate-like neural spines are inserted into the neural processes of the succeeding ora so that they are strongly articulated together. The neural processes are modified into plate-like structures which extend far forward, so that the tips reach almost to the middle next most anterior vertebra. However, in the two most anterior vertebrae the neural s are far narrower than the more posterior ones and are shaped more nearly like spines. emal spines are roughly the same shape as the neural spines and are strongly fused to the l processes of the neighboring vertebrae, just as are the neural spines and neural processes. the neural and hemal canals are very large (plates 4 and 5).

It is inferred from their form that the vertebrae of the istiophorid fishes are most table for precise movements and that sudden changes of direction are probably impossible. a well known fact that fishing boats are often attacked by spearfishes, but it is doubtful ier such attacks are made purposely. It may be that the fish strikes the boat because the ruction of the vertebrae does not give it the ability to change its course in time.

These fishes of the family Istiophoridae, with 24 vertebrae, can be further divided into rent groups. In the first group the vertebral count can be shown by the formula 12 + 12 and second group by the formula 11 + 13. Considerable differences in the form of the vertebrae of course, be detected among the species (plate 4), the proportion between the length and the t of the vertebrae differing in each species. The hemal spine of the first caudal vertebra s markedly in form from those of the more posterior vertebrae and also differs among the ies (see plate 5).

The above-mentioned two groups based on the vertebral counts have no connection at all the presently recognized classification of the istiophorid fishes. The first group includes the tnosed spearfish (Tetrapturus angustirostris), the sailfish (Istiophorus orientalis), and the

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[11] Kishinouye, K., Jour. Coll. Agri. Tokyo Imp. Univ., Vol. 8, No. 3, 1923.

Plate 3.--Crania. A - shortnosed spearfish; B - white marlin; C - striped marlin; D - black marlin.

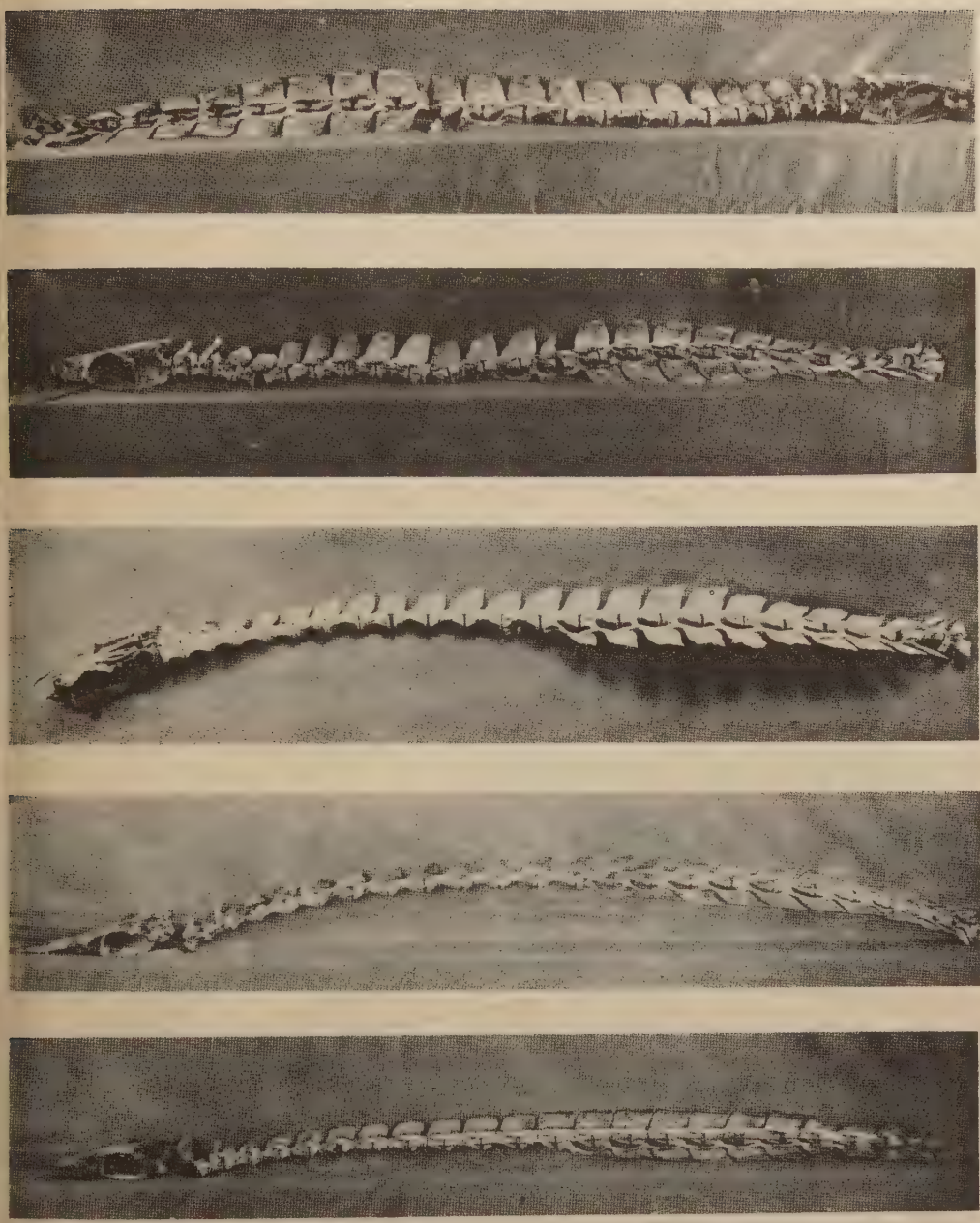
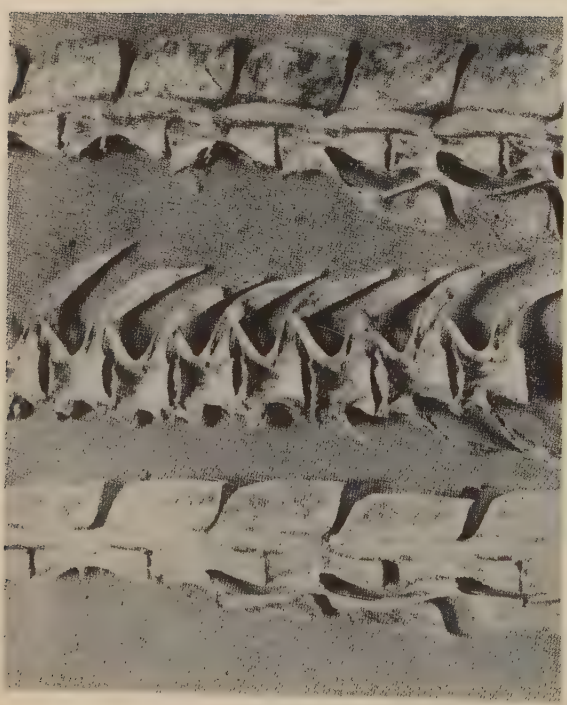


Plate 4.--Vertebrae. A - white marlin; B - black marlin; C - striped marlin; D - sailfish; E - shortnosed spearfish.

A

B



C

Plate 5.--A - membrane bones of the black marlin; B - structure of the vertebrae--from top to bottom, sailfish, broadbill swordfish, shortnosed spearfish; C - articulation of vertebrae (shortnosed spearfish).

arlin (Makaira mitsukurii), while the second group includes the black marlin (Makaira and the white marlin (Makaira marlina).

the family Xiphiidae, that is in the broadbill swordfish (Xiphias gladius), the vertebrae rkedly from those of the istiophorid fishes. Neither the neural nor hemal spines are into such flat plates; they present only a somewhat flattened spine shape. Both the d hemal processes are remarkably small and only slightly support their respective the next anterior vertebra. The number of vertebrae is also remarkably different, al of 26, of which 16 are ventral and 10 caudal, the formula being 16 + 10.

Jaws

the istiophorids the elongated upper jaw is formed of the premaxillary, maxillary, and The nasals are joined to the frontal, but the union is very weak. The lower jaw is f the articular and the dentaries, but the left and right dentary bones are not joined directly as in other fishes, there being at their anterior ends a triangular bony structure rms the sharp tip of the lower jaw and into which the dentary bones are articulated.

he upper jaw is made up in large part of the premaxillary, the maxillary itself attaining -half of the total length. It is narrow and except for the point of articulation with the is of nearly the same thickness throughout. The nasals make up the dorsal surface of jaw and extend over 3/4 of the total length. They are flat and gradually tapering and d to the premaxillary. The upper jaw is not hollow but is almost solid with a fibrous e like that seen in chips of bamboo.

Both jaws are covered with tiny cone-shaped bony teeth, but these innumerable teeth do from the jaws, nor are they attached to them. The overall appearance of these teeth rasp, and they are somewhat coarser on the outer edges of both jaws and near the r end of the premaxillary. Of course, these teeth are probably of some use when the h seizes its prey, but this objective alone does not suffice as a physiological and mor- al explanation of these teeth for the reason that the teeth can be seen to exist near the upper jaw, which is far beyond the tip of the lower jaw.

There are conspicuous differences among the species in the ratio between the lengths of r and lower jaws as measured from the posterior end of the maxillary, this ratio being he black marlin, 2.19 in the sailfish, 1.94 in the white marlin, 1.84 in the striped and 1.28 in the shortnosed spearfish (see plate 6 and table 3).

In the broadbill, the upper jaw is made up of the premaxillary, maxillary, and nasals as he istiophorids, but it is markedly different in form. The lower jaw is made up of y frailer articulars and dentaries than in the case of the istiophorids. There are no either of the jaws in adult fish.

The upper jaw is compressed, its dorsal surface flat and its ventral surface somewhat , the ventral surface being composed of the left and right premaxillaries, which are used together. The dorsal surface is composed of the maxillary and nasals, all of each the whole length of the dorsal surface. All of these bones are solidly fused together it is difficult to separate them. Regan[12] in his schematic diagram showing the structure pper jaw of the broadbill, has the nasals reaching only half way along the upper jaw, but ught that this point requires correction (figure 1). The upper jaw has a box-like hollow with regular septa forming a ladder-like pattern, presenting the appearance of a longi- y sectioned piece of bamboo.

Regan, C. T., Ann. Mag. Nat. Hist. London, Vol. 3, No. 13, p. 73.

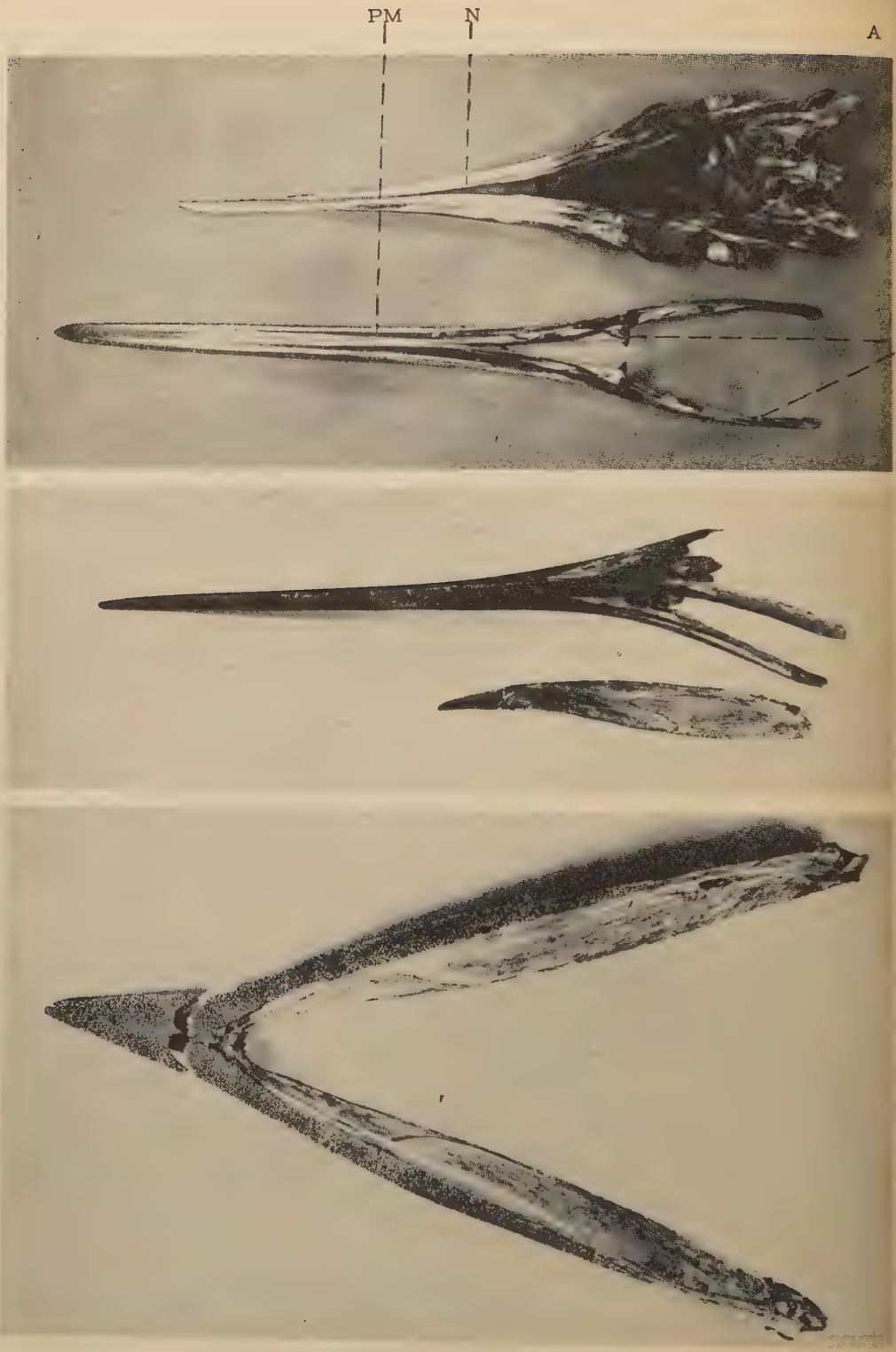
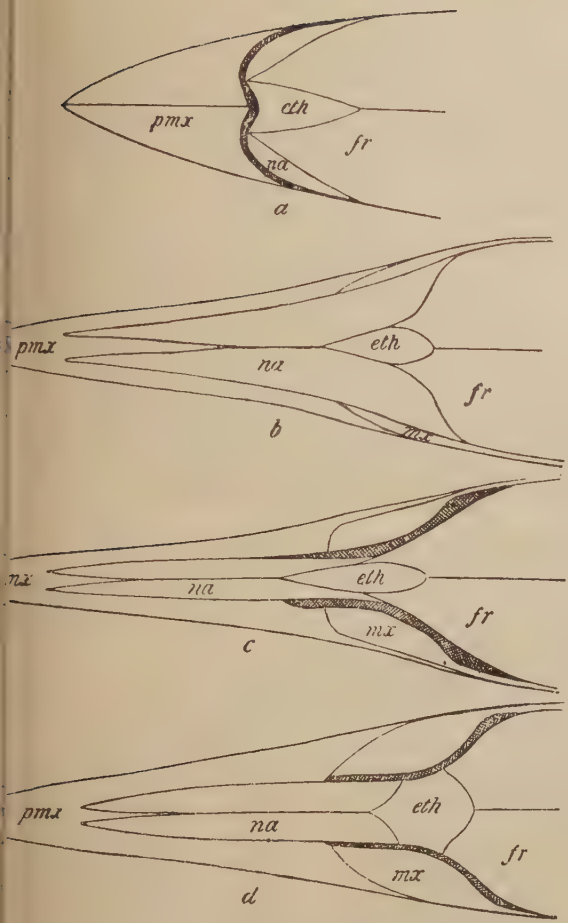


Plate 6.--A - structure of the upper jaw (striped marlin); N - nasals; M - maxillary; PM - premaxillary; B - both jaws (black marlin); C - lower jaw (black marlin).



re 1.--Structure of upper jaw (from Regan). gram showing the structure of the rostrum Acanthocybium (a), Histiophorus (b), Xiphias and Xiphiorhynchus (d). pm premaxillary, maxillary, na nasal, eth ethmoid, fr frontal.

(d) Palatines

There are no remarkable differences in the overall form of the palatines among the istiophorid fishes. There are, however, remarkable differences in the teeth which grow on the palatines, the shortnosed spearfish having several rows of fine, sharp villiform teeth, whereas in the other species there are only one or two rows which are poorly developed or vestigial (plate 7).

(e) Posttemporal and supraclavicle

The anterior portion of the posttemporal is trident-shaped and articulates with the cranium. Its posterior end is generally rounded, but has a triangular projection which extends obliquely down and rearward.

In the white marlin the posterior edge is rather triangular, and in the very middle of the broadest portion of the bone there is a somewhat slanting, conspicuous ridge, the anterior end of which projects in the form of a spine. In the black marlin the posterior end is rounded and the triangular projection is sharp. The process in the center is blunt, but along the lower edge of the bone at the base of the lowest portion of the anterior projection there is another small projection. In the striped marlin the end of the bone is roughly rounded, the central projection is rather broad, and the triangular posterior projection is broad and very close to the main part of the bone. The central process is very conspicuous and there is a deep concavity directly below it. The small projection on the lower edge of the bone which was seen in the black marlin is also present in this species. In the sailthe posterior part of the bone is markedly smaller and narrower than in the other species, riangular projection is large, and the central process is obscure. There is no projection the lower edge. In the shortnosed spearfish the posterior end of the bone is rather ellip, the triangular projection is broad and large, and instead of the central process there is a ewhat oblique deep groove.

Some differences are also to be seen in the form of the supraclavicle. In general, this is spatulate in shape with its upper edge irregular and gradually sharpening and its lower rounded. The central portion of the bone is somewhat constricted.

In the white marlin the irregular upper end is rather long and twisted downward somewhat he lower end is also irregular. In the black marlin the upper end is short and the lower end cely rounded, while the constriction of the central part is conspicuous. In the striped marlin pper end is rather like that of the white marlin, the lower end is nicely rounded, and the al part is only slightly constricted. In the sailfish the upper end is short and the portion wing it is rather expanded, the constriction of the central part is conspicuous, and the lower

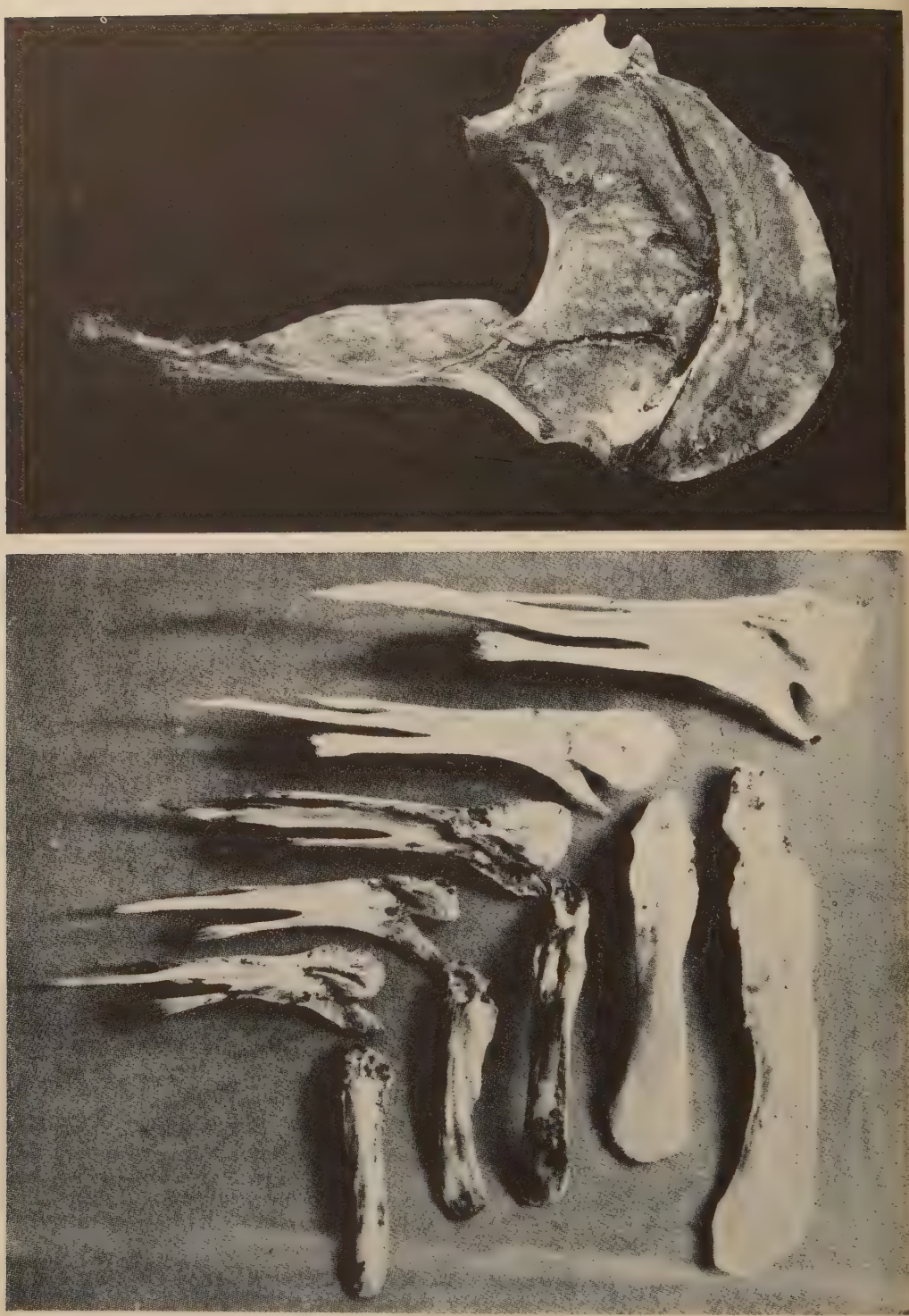


Plate 7.--A - palatine bones and their teeth (black marlin); B - posttemporals and supraclavicles--from outside in, white marlin, black marlin, striped marlin, sailfish, shortnosed spearfish.

perfectly rounded. In the shortnosed spearfish the upper portion is the shortest among species and is somewhat rounded, and the constriction of the central portion is very e; the lower end is perfectly rounded. In the broadbill swordfish these bones are com- different in for· and comparison is difficult (plate 7).

Branchiostegal rays

Conspicuous differences among the branchiostegal rays of the various species can be The number of these rays in both families of spearfishes is 7. In the white marlin the y is remarkably broad, short, and stout, with a roughly triangular form, the other rays generally long and slender. In the black marlin, as has already been stated, the branchio- membrane is short, and consequently the branchiostegal rays are also markedly shorter the other species. In the striped marlin all of the branchiostegal rays are rather fila- us, they are even slenderer in the sailfish, and in the shortnosed spearfish they are the ilamentous of all (plate 8).

In the broadbill the epihyal is strikingly large, and the branchiostegal rays are flat and d conspicuously curved.

) Pectoral girdle

As was stated earlier, in the white marlin the pectoral fins have a special direction of nent and cannot be folded back against the sides of the body. It was thought that the reason is was probably that the joint between the pectoral fins and the bones which support them a peculiar type or that there was some difference in the arrangement of the muscles.

In the white marlin the articulating surface of the supracoracoid which articulates with tinotis is almost horizontal, markedly broader than in the other species, and somewhat d anterioposteriorly. The anterior margin of the clavicle has a slight concavity on top ly a slight convexity below, being almost straight. In the other istiophorids the articu- surface of the supracoracoid with the actinotis is rather oblique, narrow, and is not twisted oposteriorly. Except in the striped marlin, the anterior edge of the clavicle has a conspi- concavity, but in the striped marlin it is straight and similar in form to that of the white n. Rather conspicuous differences between the white marlin and the other species can also en in the form of the hypocoracoid, the breadth of the shoulder girdle as a whole is greatest white marlin, and the space between the hypocoracoid and the clavicle is greater in this es than in any of the others. As for the form of the hypocoracoid, there is a process which ates at about the middle of its upper edge and which curves back running along the posterior In the white marlin the origin of the process is conspicuously large, but the process as le is blunt and quickly becomes obscure. A roughly triangular projection on the upper rear of the hypocoracoid is turned noticeably upward in the white marlin and shortnosed spearfish.

In the other species of the family Istiophoridae the pectoral girdle is in general narrow and pace between it and the clavicle is small; the process discussed above is sharp and conspi- and extends all along the edge of the bone. The upper rear edge of the coracoid /evidently coracoid is meant/ is almost horizontal (plate 9).

h) Pelvic girdle and ventral fins

The pelvic girdle and ventral fins are lacking in the broadbill. In the Istiophoridae the girdle is well developed and is rather palmate in shape. Its structure falls into two types, ich one appears in the white marlin and the other in the rest of the species. As is shown in 9, in the former the right and left sides of the pelvic girdle are fused together and are ult to separate, while in the latter type there is a broad space between the two sides and can easily be separated.

Hitherto it has been considered that the number of rays in the ventral fins was 1 to 3 in the horidae with 1 in all species of the genus Tetrapturus and 3 only in the genus Istiophorus,

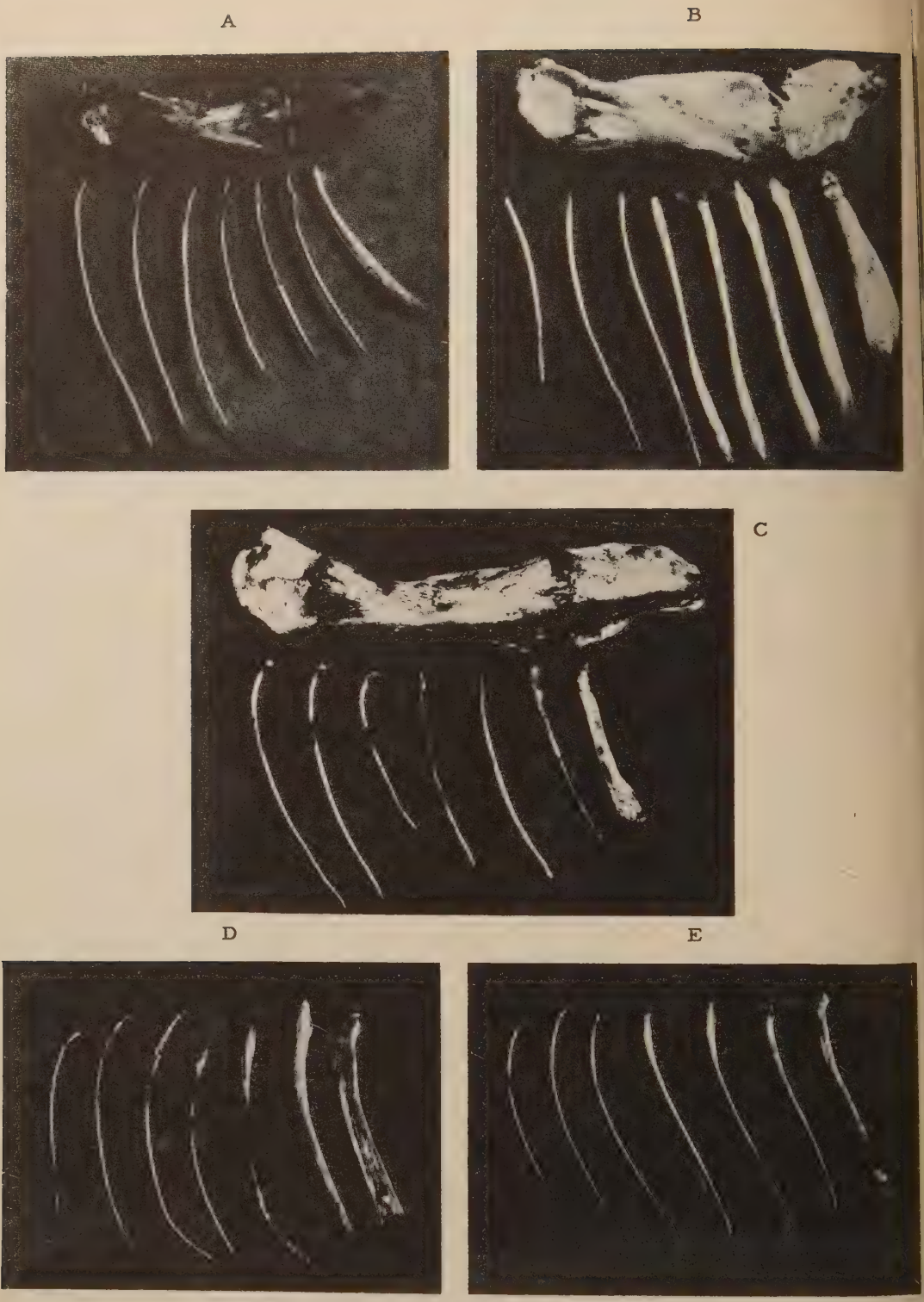


Plate 8.--Branchiostegal rays. A - striped marlin; B - white marlin; C - black marlin; D - sailfish; E - shortnosed spearfish.

A

B

C

Plate 9.--A - shoulder bones. Top row from left to right: white marlin, black marlin, striped marlin; lower row from left to right: shortnosed spearfish, and sailfish. B - pelvic girdle. On the right: black marlin; on the left: white marlin. C - pelvic girdle and ventral fin rays (black marlin).

however, as a result of the examination of a large number of specimens it appears that this probably in error, at least the fishes of the family Istiophoridae in Formosa all have 3 vent fin rays (plate 9).

3. Viscera

In the fishes of the family Istiophoridae the body cavity is very long, extending poste to the anus, and its posterior end reaches the area above the origin of the first anal fin. In broadbill the body cavity is short and wide, and its posterior end is anterior to the first anal

In the istiophorid fishes the anus is in an advanced position about the length of the fir anal base anterior to the anterior end of that fin.

In the Istiophoridae the stomach is very large, in full specimens reaching almost to a point above the anus. The opening of the intestine appears close to the cardiac orifice and th intestine itself is slender, about the size of one's thumb, and enclosed in the pyloric caeca. portion of the intestine is somewhat expanded; the intestine then makes a sharp bend, the por adjacent to the bend lying parallel to each other, and it then makes a slight curve along the ti the pyloric caeca after which it runs straight to the anus. The length is much less than the b length, the proportions being about 2.26. The contents of the intestine are simply mucus and is not possible to discover any solid object with the naked eye. The liver is rather small and covers a part of the pyloric caeca, and the gall bladder is slender and elongated. In a genera view this digestive system presents a form extremely close to that of the tunas.

The air bladder is very distinctive, being formed of many chambers like a mass of bubbles lying along the dorsal surface of the whole body cavity. The digestive organs and the gonads (except in the shortnosed spearfish) are all contained in the body cavity anterior to the anus, with only the air bladder extending posterior to the anus and reaching a point above the origin of the second anal fin. This is a point of conspicuous morphological difference betwee istiophorid fishes and the scombroids, which are considered to be most closely related to the The air bladder is composed of small chambers of irregular size, but the arrangement of the is more or less bilaterally symmetrical (plate 10).

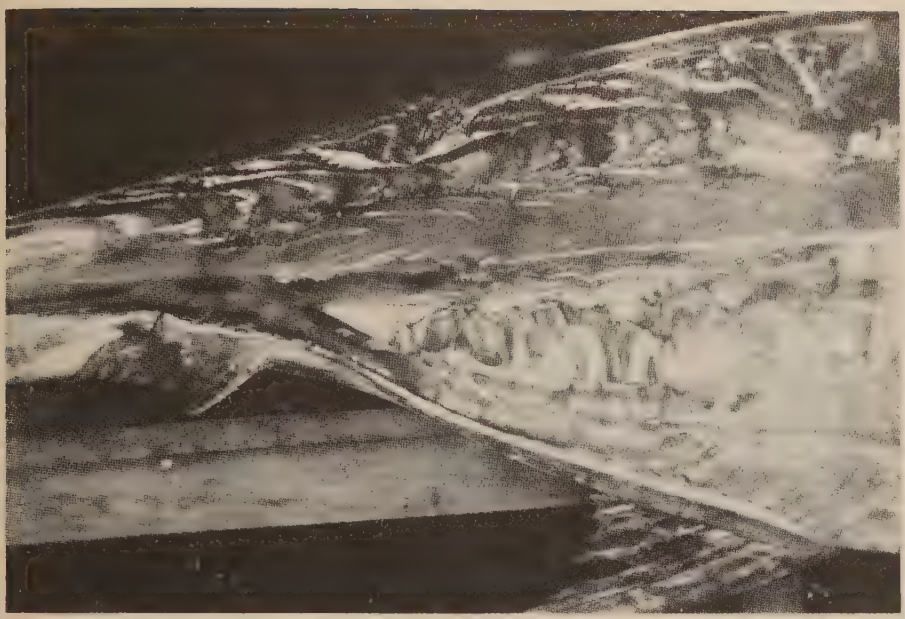
The gonads are on the whole bilaterally symmetrical, but in the shortnosed spearfish they have a peculiar structure, being Y-shaped with the right side short and its posterior end joined to the left side. The point where the two gonads are joined is directly above the anus a they open through a single short reproductive duct. The left gonad is prolonged posteriorly an in well-matured specimens it reaches the posterior end of the body cavity.[13/]

The tip of the ureter is markedly expanded, forming a part which might be called a uri nary bladder.

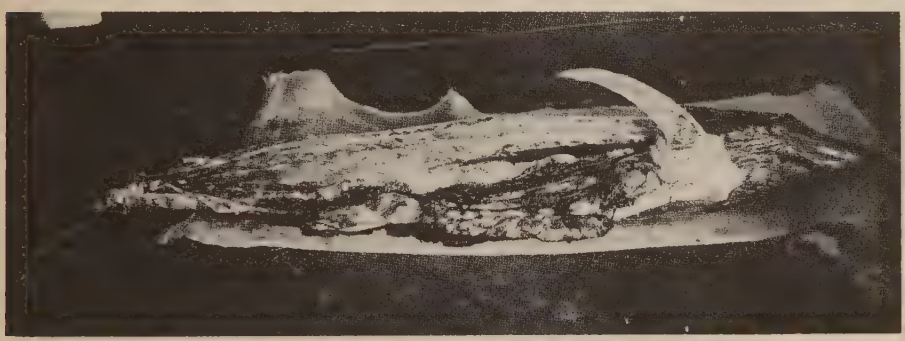
In the broadbill the body cavity is short and capacious and there is no marked differenc from the istiophorid fishes in the structure of the digestive tract. The body cavity appears on anterior to the anus, the stomach is large, the liver is small, and the pyloric caeca are also markedly smaller than in the Istiophoridae. The form of the intestine is somewhat different, flexed portion being notably shorter, and differences in thickness are apparent from the anteri to the posterior end. In the istiophorids a cross section presents a regular round shape, but i the broadbill it is irregular with conspicuous indentations and projections.

The air bladder is single-chambered and large. Its membranes are weak and it is ea destroyed.

13/ Nakamura, Hiroshi. Zoological Magazine, Vol. 49, No. 6, pp. 233-238, 1937.



A



B

C

Plate 10.--A and B - showing structure of the air bladder; C - natural food of the marlins (black marlin); the stomach contents are mackerel.

C. Classification

Jordan and Evermann[14] have been taken as the standard for classification.

Classification of the families

a. Ventral fins present with 1 to 3 rays, scales developed, all rays of the dorsal fi externally developed even after maturity. Two pairs of keels of equal size on both sides of caudal peduncle. Teeth very small and firmly attached, sword-shaped portion of upper jaw narrow and almost round in cross section. Left and right branchiostegal membranes fused together . . . . . Istiophorid

b. Ventral fins absent, scales not developed. The most posterior rays of the first d fin disappear after maturity. The caudal peduncle has a single pair of very large keels, and teeth are lost after maturity. The sword-shaped portion of the upper jaw is broad and long elliptical in cross section. The left and right branchiostegal membranes are not joined toge . . . . . Xiphiidae

a. Family Istiophoridae

Classification of the genera

a') Dorsal fin not remarkably high, anterior lobe small, whole dorsal fin well developed Body slender, upper jaw short, no spots on sides of the body. Ventral fin somewhat developed . . . . . Tetrapturu

a'a') Dorsal fin remarkably developed, ventral fins long, snout long, body slender with sp on the sides . . . . . Istiophorus

a'a'a') Dorsal fin low, its anterior lobe large, anterior spines stout. Ventral fins generally poorly developed, body stout, spots may be present or absent on the sides . . . . . Makaira

Genus Tetrapturus Rafinesque*, fūraikajiki genus

Jordan and Evermann record six species for this genus, five of them from the Indo-Pa region. However, those taken in Formosa all belong to the following single species.

1) Tetrapturus angustirostris Tanaka, fūraikajiki /shortnosed spearfish/

Plate 13, figure 1 (no Formosan name)

Tetrapturus angustirostris --Tanaka, Shigeo. Japanese Ichthyology, p. 375, 1921.

Tanaka, S. Fishes of Japan, 1, 2d edition p. 324, 1935.

Jordan and Evermann. Occ. Papers Calif. Acad. Sci. XII, p. 31, 1926.

Morphology - D. III, 11-13, XXXV-XXXVII, 6. A. II, 12., 7. V. I, 2. Vertebrae - 24 (12

Body slender and not very large, specimens over 20 kg. being rare. Body length 6.8 times body depth (measured around the sides of the body), 7.9 times body depth at the origin the first anal, and 6.28 times the length of the snout. Length of snout 1.39 times head length

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[14] Jordan and Evermann. Occ. Papers Calif. Acad. Sci., XII, 1926.

* Rafinesque. Caratteri di alcuni nuovi generi e nuove specie di animali e piante della Sicilia, 1810.

t the snout, the latter being 3.33 times the eye diameter. Upper jaw slender and short, gth being 1.28 times the length of the lower jaw (both jaws being measured from the poste- nd of the maxillary). The first dorsal is well developed, with its anterior lobe low, its l portion rather higher, and its rays filamentous. The rays of the dorsal fin are described Tanaka as being all soft rays and by Jordan and Evermann as being all spines, but the of dissection, as shown above, is that the 3 most anterior are spines, the following 8 to 9 early soft rays with branched tips, and the remaining more posterior ones are again spines. ectoral fins are comparatively short, being 0.86 times the body depth (measured as above kewise in subsequent references). The ventral fins are represented by three rays and they oderately well developed. The anus is located anterior to the first anal fin, from which it arated by a distance roughly equal to the length of the base of that fin. The second dorsal cond anal fins are of approximately the same shape and size. Along the bases of the first l and first anal fins are developed grooves in the skin in which these fins can be accom- ed. The caudal fin is broadly forked, both lobes are narrow, and there are two pairs of on the peduncle. The body has a steely color on the back, the belly is silvery white, and undary between these two colorations is comparatively well marked and runs somewhat l of the center of the sides of the body in an approximately straight line with small serra- along the boundary. There are no markings on the sides of the body. The lateral line is ly apparent and forms rather complex curves anteriorly while in the posterior part it runs t straight along the center of the sides of the body.

The upper and lower jaws have rasp-like teeth, and there is a broad area of sharp, long on the palatines. The cranium is rather narrow and the vertebrae are rather delicate, being 12 ventral and 12 caudal vertebrae.

The gonads have a characteristic form, being Y-shaped as a whole, the left side being rkably developed and extending far posterior beyond the anus. In mature ripe specimens ft gonad together with the air bladder reach to the vicinity of the posterior end of the body y. The right gonad is small and is joined to the left one in the vicinity of the anus with the oductive duct attached at the point of juncture. In the male the posterior portion of the left l is poorly developed so that the gonads form roughly a V-shape.

s

This species has hitherto been so rare in Formosa that it had no particular name, but gh the fishing experiments of the Formosan Government-General's fishery research vessel an Maru from October to December of 1935 and from October to December 1936 it was t that the species occurs in rather dense concentrations far off to the east of the island (30 to niles off shore) in the area of the Japan Current, and at the same time it was learned that it ns in that area at this season.

Genus Istiophorus Lacépède*, bashōkajiki genus

Nine species are recorded for this genus, five of them from the Indo-Pacific region; only pecies is known from Japan and only one from Formosa. Its study was undertaken with cular care because it was thought that there was ample possibility of the fishing vessels based ikao taking some other species, since they fish on far southern grounds, however, none was l in the catch other than the same species found in Japan. It is thought that the three genera 31 species of Istiophorus recorded by Jordan and Evermann may perhaps be reduced to a far ler number of species through detailed studies. Only the following single species occurs in nosa.

Istiophorus orientalis Temminck and Schlegel, bashōkajiki /sailfish/; basho, baren (throughout the island); Formosan names 雨傘魚 (Keelung), 雨傘旗魚 (Suō).

Plate 13, figure 2

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* Lacépède. Hist. Nat. Poiss., III, 274, 1803.

Istiophorus orientalis --Tanaka, Shigeo. Japanese Ichthyology, p. 373, 1921.

Tanaka, Shigeo. Illustrated atlas of useful, harmful and admirable aquatic animals and plants, 1933.

Jordan and Evermann. Occasional Papers, Calif, Academy of Sci. XII, page 46, 1926.

Morphology - D. III, 9, XXXII-XXXV, 6-7. A. II, 11, 6. V. I, 2.
Vertebrae-24 (12 + 12)

Body length 3.19 times head length, body depth 6.3 times body depth (a), 7.8 times bo depth (b); head length 1.40 times snout length and 7.6 times interorbital space.

(a) Regular body depth.
(b) Body depth at the origin of the 1st anal. Subsequent references to body depth will be to thi measurement.

The length ratio of the jaws measured from the posterior end of the maxillary is 2.19, and the ratio of snout length to the length of the head without the snout is shown by 2.83. The body is conspicuously compressed in the anterior part, but in the caudal region it becomes almost cylindrical. There are two pairs of keels on the caudal peduncle. The 1st dorsal fin is greatly developed and high and has rather strong spines in its anterior portion. The length of 3rd spine is slightly more than 1.3 times the body depth. The 1st dorsal fin profile is high in front and gradually curved in a concave shape after which there are again very long large spine dropping off gradually in the form of an arc to the end of the fin. The pectoral fins are well developed, their length being 1.1 times the body depth. The ventral fins are the most highly developed among the istiophorid fishes, their tips extending approximately to the anus. The second dorsal and the second anal are approximately the same shape; the number of rays in the former is 6 to 7, in the latter 6. The caudal fin is greatly developed; its upper and lower lobes are long and narrow and meet at a large angle. The dorsal surface is a deep purple black and the belly is brownish. There are more than 10 transverse bands of cobalt spots on the sides. Black spots the size of soy beans are scattered over the 1st dorsal fin. The vertebral formula is 12 + 12 and all of the vertebrae are long. The rasp-like teeth are developed in both jaws, bu the teeth on the palatines are poorly developed and vestigial, and there is only one row of them.

Among past reports of the ray counts for the dorsal and anal fins, Dr. Tanaka gives 44 soft rays for the 1st dorsal, 6 rays for the 2nd dorsal, 10 soft rays for the 1st anal, and 6 soft rays for the 2nd anal, while Jordan and Evermann give 41 for the dorsal. The results of the author's study differ quite markedly from these, but since there are no other important morpho logical differences this fish is considered to be the same species as Istiophorus orientalis of Japan proper. Hitherto the ventrals have been considered to have only one ray, however, it ha been ascertained by dissection that this is an error and it should be corrected to 1 spine and 2 soft rays. The second dorsal fin has 6 to 7 rays, 7 in most specimens, with 6 fish out of a sample of 8 having 7 rays in the fin.

Habits

The seasons of migration of this species are completely different from those of the othe istiophorid fishes. It is most abundant in the waters adjacent to the island in the summer and characteristically approaches very close to the coast. Unlike other species, the catch remains comparatively high throughout the year. The juveniles are remarkably phototropic and are oft taken as they congregate around a night light. The fish which migrate into the waters around t island in the summer have rather highly developed gonads.

Genus Makaira Lacépède*, makajiki genus

All of the most important spearfishes in Formosa are included in this genus. Of the 16 known throughout the world, 3 appear in Formosan waters.

Key to the species

' Pectoral fin can be placed parallel against the side of the body, markings on sides of the body.

' Pectoral fins large and long, dorsal fin high, body rather conspicuously compressed laterally, length of upper jaw does not attain twice the length of the lower jaw. . . . . striped marlin or red marlin (makajiki or akajiki)

'' Pectoral fins long and large, dorsal fin rather low, degree of lateral compression of body not marked. Body very much rounded in the vicinity of the first anal fin, length of upper jaw more than twice length of lower jaw. ... black marlin (kurokajiki or kurokawakajiki)

'' Pectoral fins form a right angle with side of the body and cannot be folded back against the body without breaking the joint; no markings on the sides of the body. . . . . white marlin (shirokajiki or shirokawakajiki)

kaira mitsukurii Jordan and Snyder, makajiki /striped marlin/

Plate 14, figure 1

akajiki or aka (Suō, Keelung, Takao); Formosan names 紅肉旗魚 or 紅肉丁版 elung).

trapturus mitsukurii -- Jordan and Snyder. Jour. Coll. Sci. Imp. Univ. Tokyo, 1901.

Tanaka, Shigeo. Japanese Ichthyology, p.374, 1921

Tanaka, Shigeo. Illustrated atlas of useful, harmful, and admirable aquatic plants and animals, p. 163. 1933.

akaira mitsukurii--Jordan and Evermann. Occ. Papers Calif. Acad. Sci. XII, 1926.

orphology - D. III, 12-15, XXII-XXV, 6. A. II, 12-13, 6. V. I, 2. Vertebrae- 24 (12 + 12)

The body appears rather conspicuously compressed laterally in the anterior portion and es almost cylindrical in the caudal portion. The body depth is rather small and diminishes markably high rate to the origin of the first anal fin. Body length is 2.6 times the head , 5.23 times the body depth (a), and 6.9 times the body depth (b). The head length is 1.5 the snout length and 6.12 times the interorbital space. The length of the upper jaw is 1.85 the length of the lower jaw, and the ratio of the snout to the rest of the body is 2.80. The ce from the eye to the origin of the 1st dorsal fin is 4.1 times the eye diameter. The body s 4.9 times the caudal peduncle, which is a remarkably small ratio compared to the other of the genus Makaira. The dorsal fin is well developed, its anterior lobe is high, and the ior portion is much better developed than in the other species. The height of the first dorsal roximately equal to the body depth; the pectorals are greatly developed, their length exceed- body depth, which is in the proportion of 0.95. The anal fin is also well developed, and udal fin is of normal form.

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acépède. Hist. Nat. Poiss., IV, 683, 1803.

The vertebral count is 24 (12 + 12), differing from the other species of the genus Maka which have 11 + 13. The palatine teeth are vestigial and the branchiostegal rays are slender. In life the dorsal surfaces are dark purple in color and the ventral surfaces are silvery white. There are no markings other than a dozen or so clearly apparent transverse cobalt bars on th sides of the body.

This is the smallest and the highest priced fish of the genus Makaira.

Habits

This fish is very abundant around the island throughout the whole fishing season, and it is occasionally but rarely taken in fixed gear in the summer. It is present in greater or lesse numbers around the island throughout the year. Those taken during the winter at distances fro 30 to 300 miles off the coast are generally very small, large ones being taken in the coastal zones within 30 miles.

4) Makaira mazara Jordan and Snyder, kurokajiki /black marlin/

Plate 13, figure 2

Kurokajiki or kurokawakajiki (throughout the island); Formosan names 烏(黑)皮旗魚 (Suc 鐵皮丁版 (Keelung).

Tetrapturus mazara--Jordan and Snyder. Jour. Coll. Sci. Imp. Univ. Tokyo, 1901.

Tanaka, Shigeo. Japanese Ichthyology, p. 375, 1921. (kurokawa) Asano, Kōtaro. Illustrated classification of aquatic animals, 1933.

Tetrapturus mitsukurii (?)--Tanaka, Shigeo. Illustrated atlas of useful, harmful, and admirable aquatic animals and plants, p. 163, 1933.

Makaira mazara--Jordan and Evermann. Occ. Papers Calif. Acad. Sci. XII, p. 53, 1926

Morphology - D. III, 14-16, XXIII-XXVII, 7. A. II, 14, 7. V. I, 2. Vertebrae-24 (11 + 13)

The body is not as compressed laterally as in other species but is rounded, the body depth increasing somewhat in the vicinity of the 1st anal fin. Body length is 2.76 times the head length, 4.56 times the body depth (a), and 5.68 times the body depth (b). The head length is 1.5 times the snout length, 5.7 times the interorbital space, and the distance from the upper poster edge of the eye to the origin of the 1st dorsal fin is 4.22 times the eye diameter. The upper jaw is 2.21 times the length of the lower jaw, and the ratio of the snout length to the rest of the body is 2.97. The body depth (a) is 5.9 times that of the caudal peduncle. The anterior part of the 1 dorsal fin is well developed, but it gradually becomes lower posteriorly; the anterior fin rays a stout. The body depth is about 1.5 times the height of the 1st dorsal. The body depth is 1.2 tim the length of the pectorals, which are well developed. The ventral fins are poorly developed an small. The anal fin is well developed. The caudal fin is broadly forked, and both its upper and lower lobes are narrow. The caudal peduncle bears two pairs of keels, an upper and a lower. The dorsal surfaces of the body are dark purple, the ventral surfaces are brownish, and the bo as a whole has a conspicuously blackish tinge which gives it its name kurokawakajiki or "black skin spearfish." In life the dorsal fin is a beautiful cobalt color, but it turns black if exposed f long to the air. The sides of the body have obscure transverse bands made up of cobalt spots, spots running together. The lateral line is rather complexly curved in the anterior portion, bu the posterior part runs straight.

The vertebral count is 11 + 13, both jaws have rasp-like teeth, and the palatine teeth ar poorly developed and vestigial. The pectoral girdle is narrow and its anterior margins are con spicuously concave. The branchiostegal membranes are short and the branchiostegal rays ar

The Japanese name of this species was formerly given as mazara, but since it is lly called kurokawa or kurokajiki, I have assigned it the common name kurokajiki as nore suitable.

This fish is much less common in Formosan waters than the other species, however, the ncreases somewhat around the fishing season, that is, in February and March. The of the work of the Shōnan Maru in the East Philippine Sea, June to August 1937, showed s species is very plentiful there at that season. There is also at this season a great dis- in the sex ratio, females being extremely rare.

kaira marlina (Jordan and Evermann) white marlin, shirokajiki (new name)

Plate 15, figure 1

rokawakajiki or shiro (Suō, Keelung, Takao), katahari (whole island); Formosan ne 立翅旗魚 (Suō).

kaira marlina--Jordan and Evermann. Occ. Papers Calif. Acad. Sci. XII, p. 59, 1926.

trapturus mitsukurii (?)--Tanaka, Shigeo. Illustrated atlas of useful, harmful, and lmirable aquatic animals and plants, p. 163, 1933.

orphology - D. III, 10-12, XXIII-XXV, 7. A - II, 10-11, 7. V - I, 2. Vertebral ount-24 (11+ 13).

Body very stout, gigantic specimens are not unusual. The dorsal profile anterior to the orsal fin, where the body depth is greatest, projects conspicuously, for which reason the s the name of katahari (square shoulders).

The body length is 2.17 times the head length, 4.46 times the body depth (a), and 5.85 the body depth (b). The head length is 1.52 times the snout length and 5.75 times the bital space. The length of the upper jaw is 1.95 times the length of the lower jaw. The jaw is short, the proportion of the length of the head minus the snout to the snout length species being 3.14. The distance from the eye to the first dorsal fin is 4.33 times the ameter. The caudal peduncle tapers down sharply and the ratio between its depth and the epth is 6.12. The development of the dorsal fin is inferior to that in other species, the o the body depth being 1.61. A number of the most anterior rays of the fin are conspicu- hickened, and because the more posterior rays diminish in length sharply, the fin presents picuously falcate shape. The pectoral fins are quite well developed, and because they out from the sides of the body at a right angle, they have gained for the fish the Formosan of "erect wing spearfish." The proportion of the length of these fins to the body depth is The ventral fins are very small. The first anal fin is suitably developed, as are the dorsal and the second anal, both of which have 7 fin rays. The caudal fin is of a normal and there are two pairs of projections, an upper and a lower, on the caudal peduncle.

The vertebral count is 24 (11 + 13), and the palatine teeth are quite vestigial. The more r branchiostegal rays are long and slender, but the more posterior ones are markedly ed, the most posterior ray being almost triangular in shape. The pelvic girdle, unlike f other species, has the right and left sides fused together so that they are difficult to te. The pectoral girdle is broad and has a peculiar form. The upper jaw is somewhat r than in other species and is flattened so that its cross section is elliptical.

In life the dorsal surfaces are steel blue and the belly is white, and before the slime has he body as a whole presents a rather milky white color, accounting for the name "white- marlin." The dorsal and anal fins are a clear cobalt blue, the pectorals and the caudal dark purple, and there are no markings of any sort on the sides of the body. In fish which

have been exposed to the air for a long time and from which the slime has completely been removed, the dorsal surface is sometimes seen to show vestigial pale transverse bands.

Habits

This species is the most abundant around this island, being particularly numerous ea in the fishing season. Its distribution appears to be comparatively restricted to coastal are and it is rather rare off shore. At times when the direction of the wind changes suddenly an the monsoon begins to blow strongly, there appears to be a particular increase in the numbe these fish rising to the surface, and during such weather the spearfish catch of the harpoon b is usually made up almost entirely of this species.

The Makaira marlina recorded by Jordan and Evermann was based on a photograph ar can hardly be said to be satisfactory. Its distribution is given as the Pacific coast of Mexico from Cape San Lucas south. In its skeleton and in its form this species differs conspicuously from the other species of the genus Makaira, particularly marked differences appearing in th construction of the pectoral fins, the form of the pectoral girdle, and the morphology of the p girdle. It may even be thought proper to establish a separate genus in which to place this spe It is the author's intention to take up this point when further studies have been carried out in future. This is a new species for Japan. In accordance with the usage of the commercial fis men I have given it the name shirokajiki or white marlin.

Family Xiphiidae, mekajiki family

This family has one genus with one species, which is universal in distribution.

6) Xiphias gladius Linné, mekajiki /broadbill swordfish/. Tsun (Suō, Keelung, Takao); Form names 丁版舊旗魚 (Suō); 白肉丁版 (Keelung).

Plate 15, figure 2

Xiphias gladius-- Jordan and Evermann. Occ. Papers Calif. Acad. Sci. XII, p. 71, 1926.

Tanaka, Shigeo. Japanese Ichthyology, Vol. I, p. 375, 1921.

Morphology - D. III, 9, XXVI, 4. A. II, 7, IX-X, 4. Vertebrae-26 (16 + 10)

Body approximately cylindrical, snout very long, one pair of large keels on the caudal peduncle. Caudal peduncle somewhat flattened horizontally. The body length is 1.85 times th head length, 5.18 times the body depth (a), and 5.92 times the body depth (b). The ratio of th lengths of the upper and lower jaws is 3.79, and the head length is 8.69 times the interorbital space. The dorsal fin is high, being in the ratio of 1.07 with the body depth, and the pectoral fins are short, being in the ratio of 1.32 with the body depth. The second dorsal and second a fins are small, the caudal fin is large with both its upper and lower lobes rather broad and th angle small; the ventral fins are lacking.

The upper jaw is hollow in the center; the maxillary, premaxillary, and nasals are all strongly fused together and all reach to the tip of the snout. The form of this snout differs strikingly from that of the fishes of the family Istiophoridae. The form of the rest of the skel is also completely different, so that comparison with the istiophorid fishes is difficult. The b cavity is short and spacious, and the air bladder is single-chambered and large.

The coloration is a dark blackish brown on the dorsal surface and rather yellowish on ventral surface. The boundary line between these two types of coloration is not as well mark as it is in the istiophorid fishes, the color of the dorsal surface gradually fading into the colo the ventral surface. There are no scales on the body, only the skin on some parts of the pect region having a feeling like sharkskin to the touch.

'he life history of this species is known, but in Formosa it is not possible to acquaint :vith it. In general this species is rather rare in Formosa, an occasional one being landed [. It is thus not an important species. It appears that in the waters off eastern Formosa :n only extremely rarely and is not an objective of the harpoon fishery but is taken by the fishery. According to conversations with experienced fishermen, when this species is nd dies in the water it immediately floats to the surface and does not sink like the other hes.

OLOGY

A. Migrations

There are a great many things that are not known about the habits of the spearfishes. vill deal chiefly with the migrations of the spearfishes in Formosan waters.

n the conduct of such a special sort of fishery as the harpoon fishery, the habits of the hes are skillfully utilized. When the wind and waves are high, the spearfishes rise to ace of the water and swim there with their dorsal fins projecting. According to experi- shermen, this surfacing of spearfish is most often seen when the current and the wind are in exactly opposite directions, and no fish are seen at the surface at all when the current wind are running in the same direction. It is said that in many cases the direction in irfaced spearfish swim coincides with the wind direction and runs counter to the direction irrent. However, this does not mean that when such conditions prevail the spearfishes ie surface all of the time; it is said that they come up temporarily, and that when they come up they all come up at once.

In the waters off eastern Formosa, where the Japan Current passes, the current flows ith a slight easterly component. From October to March the northeast monsoon blows ntinuously in a direction just opposite to that of the current, and if we are to adopt the of the fishermen's experience, this sea area must be said to be a well-suited ground for h fishing.

Judging from the results of several years of commercial fishing experience, in the winter nal distribution of atmospheric pressures breaks down and weak lows arise or pass the waters north of Formosa, and at such times the monsoon stops blowing, there are utherly winds, and the sea surface becomes calm and the sky clear. In such weather the rcial boats stay in port and give up going fishing. Such weather ordinarily continues for ays, and as the lows move away and dissipate, strong high pressures appear in the ian region, and with the return to normal of the distribution of atmospheric pressure, d direction changes suddenly and the monsoon begins to blow strongly. When there are udden shifts in the wind direction, the spearfishes come to the surface in the greatest s and many specimens much larger than those ordinarily caught are taken, the white marlin ng to be most numerous among them. The fishing boats usually leave port before dawn urn in the evening, but in cases where the boats have failed to go out fishing because the utherly winds were blowing before dawn (these winds are called "maji" or "maze"), if s such a sudden change in the weather they will go out at any hour and it not infrequently s that they make big catches.

The spearfishes are probably present in Formosan waters at all times of the year, but s no doubt that the fact that they are particularly abundant at certain seasons is due in neasure to seasonal changes in oceanographic conditions. However, the fact that they throughout approximately half of the year, forming dense schools in the waters off eastern sa, is difficult to account for simply by the direct effect of oceanographic changes.

The fishing season for spearfishes begins in the south and moves gradually north, usually around March or April in the vicinity of Hōkasho. We have the following oceanographic r this area:

Table 3.--Water temperatures and specific gravities on the line from Suō to Yonakuni Island (averages from the surface to the 100 m. level; the underlined figures are at the height of the fishing season)

Months	Water temperatures	Specific gravities
1	22.7	25.67
2	22.7	25.80
3	22.6	26.00
4	23.3	25.98
5	24.3	25.79
6	25.3	25.98
7	26.1	25.82
8	26.2	25.79
9	26.4	25.35
10	25.6	25.69
11	25.0	25.69
12	24.2	25.87

Table 4.--Regular station observations at Hōkasho (1935)

Months	Water temperatures	Specific gravities
1	17.38	25.18
2	19.43	25.35
3	19.30	25.47
4	23.70	25.21
5	23.23	25.07
6	26.62	24.38
7	27.37	24.14
8	26.73	24.83
9	25.32	24.75
10	24.15	24.65
11	21.85	24.79
12	21.08	25.40

Table 5.--Regular station observations at Shinkō (1935)

Months	Water temperatures	Specific gravities
1	22.0	25.31
2	23.5	25.24
3	23.9	25.64
4	25.0	25.47
5	26.4	25.62
6	27.0	25.33
7	27.9	24.62
8	26.4	24.40
9	27.2	24.50
10	26.8	25.37
11	25.2	25.62
12	23.2	25.62

Table 6.--Regular station observations at Garanbi (1935)

Months	Water temperatures	Specific gravities
1	21.6	23.58
2	23.5	23.60
3	23.1	23.62
4	25.2	23.05
5	26.9	25.57
6	27.3	23.84
7	27.7	24.14
8	27.5	23.51
9	27.4	24.07
10	27.0	20.93
11	25.1	22.22
12	22.9	23.52

Among the foregoing oceanographic data, the figures for the line from Suō to Yonakuni are averages for the past 12 years. In general, the waters east of Taiwan ordinarily igh specific gravities in the winter and low specific gravities in the summer, but the s are not regular as they are in the case of the changes in water temperature. The spear- are said to swim in comparatively shallow layers of the sea, and the construction of the dder is suitable for this. At Hōkasho there is comparatively little influence from the nd so that the water temperatures and specific gravities observed there should not differ from those of the waters farther off shore. It must be said that on the basis of these graphic data it is difficult to give an accurate explanation of the presence of the spear- during half the year in the waters east of Formosa. Consequently, it is difficult to explain grations of the spearfishes in terms of the direct effect of seasonal changes.

As will be set forth in a later section, it is clear that, except in the case of the sailfish e shortnosed spearfish, the spearfishes which migrate into Formosan waters do not do so e objective of spawning.

It being thus difficult to account for the migration of spearfishes in Formosan waters as controlled by spawning or seasonal changes, it is necessary to consider some other cause. ause, which, of course, will be subject either directly or indirectly to seasonal effects, at this season in this area the fishes upon which the spearfish feed are present in abun- From October to March great schools of scad and mackerel are scattered through the east of Taiwan. The mackerel in particular form a great concentration from the Suō banks Kisantō region, and during the peak season of February and March they are taken in very quantities by longline boats based at Suō, the catch for one day not infrequently exceeding 00 fish. According to the statistics for 1934, the yearly catch amounted to 2,477,600 kin value of 115,459 yen. These mackerel are not only in themselves an important objective shery, but they are also utilized as bait for the longline fishery, and it is thought that they lay an important role in keeping the spearfishes in this sea area over a long period of time. nown that if we investigate the stomach contents of the spearfishes taken during this fishing n, they are almost completely made up of mackerel (see plate 10).

The species which have been known to occur around this island since ancient times are the sh, white marlin, black marlin, and striped marlin, and the broadbill swordfish, little been known about the distribution of the shortnosed spearfish. It was in 1935 that it became that the shortnosed spearfish also occurs in the vicinity of this island. In investigations ed on in that year from October to December by the research vessel Shōnan Maru of the n Government-General, two shortnosed spearfish were taken in the waters east of the island. became clear that this species also occurs in Formosan waters. Investigation was made d out whether they were ever landed in the various markets, and it turned out that they were

only very occasionally brought into Suō. It was found out that there was no name applied to th species and that in the market they were handled as if they were sailfish. From October to December of 1936 the same vessel carried out another investigation of the same sea area and took 26 specimens of this species. The research vessels Shichisei Maru of Taihoku Provinc and Takao Maru of Takao Province, carrying out cooperative investigations in the sea areas the north and south, also took several specimens of this species, so that its distribution was gradually clarified.

There are no essential differences between the longline gear used by research vessels that used by commercial fishing boats, nor does it seem likely that the bait used is so differe to cause a difference in the catch. Consequently it must be thought that the fact that this spec is not taken by commercial fishing boats but has been taken only by research vessels is due to fact that they operated in different sea areas. Actually, the research vessels fished from 30 miles to 300 miles off shore but principally at about 150 miles off the coast, while the operati area of the commercial boats is restricted to a range of 30 miles from shore. Consequently we can conclude that the shortnosed spearfish occurs only in the far off shore waters. Furthermo as the vessels get farther off shore they catch fewer of the large fish that are taken along the coast, and even most of the fishes of the genus Makaira that they take are very small. The following table gives statistics on the spearfish catch by months and by species for the Suō market in 1934 and 1935.

As is clear in the following table, in the waters east of this island the migrations of the spearfishes, except for the sailfish, are entirely limited to the winter monsoon, while the sail fish is taken throughout the year and is always present around the island, although it is more abundant in the summer. As will be detailed later in the section on the fisheries, from April t July everywhere on the east coast of Taiwan a large number of large set nets are used. The manner of using these set nets differs from place to place, but because on the east coast of Formosa the bottom falls off steeply the nets are placed very close to the shore. Sailfish are occasionally taken in these set nets. Very rarely a striped marlin is also found among the catc of the set nets, but for the most part the only spearfish they take is the sailfish. Consequently it is thought that the sailfish has the habit of coming in very close to the coast. Other fisheries also take considerable numbers of this species in the summer, a fact which it can be thought shows that the distribution of this fish in the waters around Formosa differs completely from th of other species in that it is comparatively densely present in the summer.

If we look at the statistics for several years' landings of spearfishes in the Suō market, can see a tendency for white marlin to predominate overwhelmingly in the early part of the seas with striped marlin increasing gradually in the middle of the season until they equal the white marlin in numbers, and with black marlin appearing in large numbers at the end of the season. The appearance of the black marlin is for only a very short period of time, the striped marlin's season is next shortest, and the fishing for white marlin continues over a rather long time. Sail fish appear in considerable numbers comparatively abundantly throughout the year. According to the investigations of the Shōnan Maru from June to August of 1937, at this season large numbe of black marlin were taken in the Kuroshio Current area of the East Philippine Sea, and it is interesting to note that among the fish taken over 80 percent were male, females being very rar in the catch. Furthermore, the gonads of both the females and males were very immature. Th larger fishing boats based at Takao operate in the vicinity of Hainan Island from April to June fishing longlines for black marlin, and it is reported that among the fish taken on this fishing ground there are not a few which have their gonads completely developed and are engaged in spawning.

To summarize, if we consider the occurrence and migrations of the istiophorid fishes in Taiwan waters according to genera, the fishes of the genus Makaira are abundant in the winter i the area of the Japan Current rather close to shore; the shortnosed spearfish we know little abo because there have been no investigations at other seasons of the year, but it is also abundant in the winter in the Japan Current area. However, it is markedly pelagic and its occurrence is limited to the far off-shore waters. The sailfish is abundant around the island throughout the ye but is particularly abundant in the summer, and its migrations extend very close to the coast.

Table 7.--Numbers of spearfishes handled at the Suō market (by months and by species; upper figure is for 1934, lower figure for 1935)

Month	White marlin	Striped marlin	Black marlin	Sailfish
1	1,446	604	156	65
	1,401	1,488	80	180
2	1,202	244	423	20
	902	913	258	181
3	1,361	225	223	24
	1,013	502	250	115
4	331	310	11	253
	462	97	169	97
5	107	12	29	334
	34	5	5	179
6	12	3	17	530
	6	6	3	256
7	4	4	7	308
	0	0	0	18
8	11	1	30	253
	0	0	0	0
9	8	5	9	58
	4	5	3	46
10	648	632	49	784
	205	420	145	229
11	1,990	814	86	236
	1,546	926	212	550
12	1,267	1,030	116	61
	2,787	2,458	149	267
	8,387	3,884	1,156	2,926
	8,360	6,820	1,274	2,118

The broadbill swordfish is taken only rarely around the whole island, the greatest number dings being made at Takao; these landings, however, are not numerous enough to be recorded statistics. At Suō in most years they are very rare, but in November and December of 1936 were rather abundant and several were landed every day.

B. Spawning Habits

It appears that except for the broadbill swordfish almost nothing has been recorded con- ng the life history of the spearfishes. In Taiwan large numbers of spearfishes are landed ey migrate in rather dense schools into the waters east of the island, but these migrations lmost no direct connection with spawning. However, among the sailfish and shortnosed

spearfish some specimens which are about to spawn or are engaged in spawning are discover
The author has previously made some observations in the South Seas[15] on the ripe eggs of t
sailfish. The juvenile sailfish have a strongly marked positive phototropism, and in the wat
east and south of the island they are taken from time to time with night-lights. The fishery
experiment stations of both Takao Province and Taihoku Province have specimens under 20 c
in length which were taken in this manner, and in this laboratory several specimens of about
30 cm. are preserved that were taken in the same manner off Hong Kong. Among the sailfis
that are taken in set nets along the coast of eastern Taiwan in the summer there are individu
with highly developed gonads. Of course, they are still quite a way from having ripe eggs, b
it is thought that they are not too far off from spawning. Considering the appearances of juve
and the degree of ripeness of these ovaries, it is possible to imagine that the sailfish spawn
somewhere not very far from Taiwan.

Among the spearfishes which migrate into the waters east of Taiwan in the winter, the
gonads are very immature and in many cases it is difficult to distinguish the males and femal
with the naked eye, but it is clear that spawning is being carried on by the shortnosed spearfi
occurring farther off shore[16].

The research vessel Shōnan Maru of this laboratory on November 22, 1936, fished a
station at 21°46'30"N., 124°22'30"E., and at 2:00 P.M. one shortnosed spearfish was brough
aboard still alive. When lifted out of the water, the fish released eggs all over the deck. Thi
fish was captured on a branch line 60 m. long, and since wooden floats had been placed above
each of the branch lines, the depth at which the fish was hooked was not greater than 60 m. S
it is probable that because of the force of the current the branch lines hang at somewhat of a
angle in the water, in actuality the depth at which the fish bit was probably 10 or 20 percent le
than 60 m. The observations recorded in the field notebook were as follows:

The air temperature at the station at noon that day was 24.6°C., atmospheric pressur
was 763 mm., the sky was clear, surface water temperature was 25.8°C., as was that at the
60 m. level. A thermometer inserted into the anus of the shortnosed spearfish showed a body
temperature of 25.4°C. The snout of the fish was slightly broken, but the distance from the ti
of the snout to the keels on the caudal peduncle was 1,524 mm. and the weight of the fish was
12.3 kg.

The eggs that were released were preserved in alcohol and brought back, but as they ha
already become white and opaque it was not possible to see their internal structure. The size
the eggs was about 1 mm. The ovarian eggs of this specimen were preserved by freezing toge
with the fish and when they were looked at later it was found that they were very poorly develop
the eggs were small, and the oil globules were clustered like grapes (plate 11). At the same ti
a number of other specimens captured were investigated and the majority of them had the gona
either ripe or nearly ripe so that it was possible to make observations of a large number of rip
eggs. The eggs in the ovaries that were thought to be nearly mature were almost colorless an
translucent and the yellowish-brown oil globules had united until there were only two of them
(plate 11). The eggs at this stage of development had a diameter of about 0.8 mm. According
the observer who witnessed the release of the eggs they were released in a whitish mucus and
were almost colorless and clear.

The gonads of both males and females are of a peculiar form as was pointed out in secti
I (plate 11).

There is thus no doubt that spawning of the shortnosed spearfish takes place off the eas
side of the island, but we may consider further that the spawning of the spearfishes probably d
not, as in other fishes, take place in great groups over a very short period of time, but probab
continues over a long period and over a broad area of the sea. The reason for this belief,

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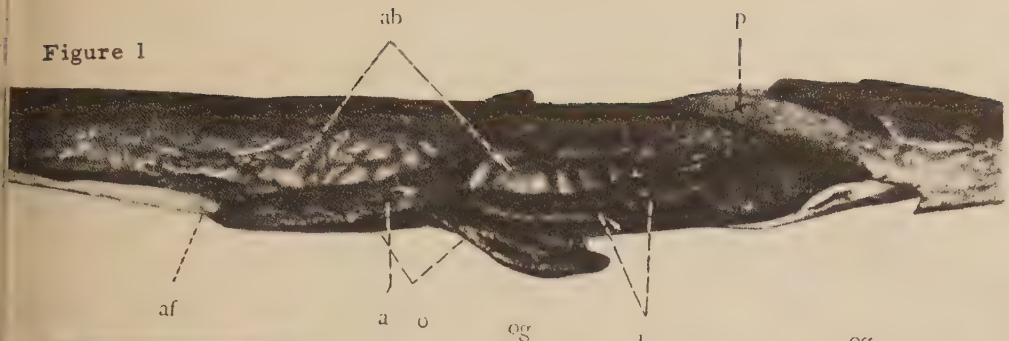
[15] Nakamura, Hiroshi. Zool. Mag. 44, 244, 1932

[16] Nakamura, Hiroshi. Zool. Mag. 49, 233-238, 1937

Figure 1



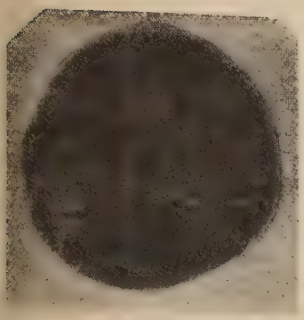


Figure 2

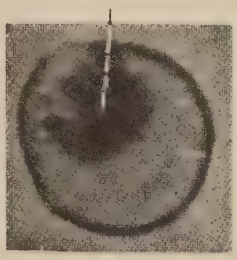


Figure 3

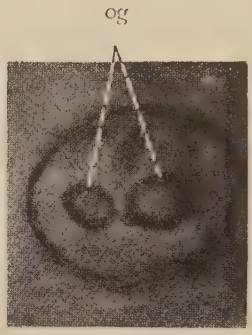


Figure 4

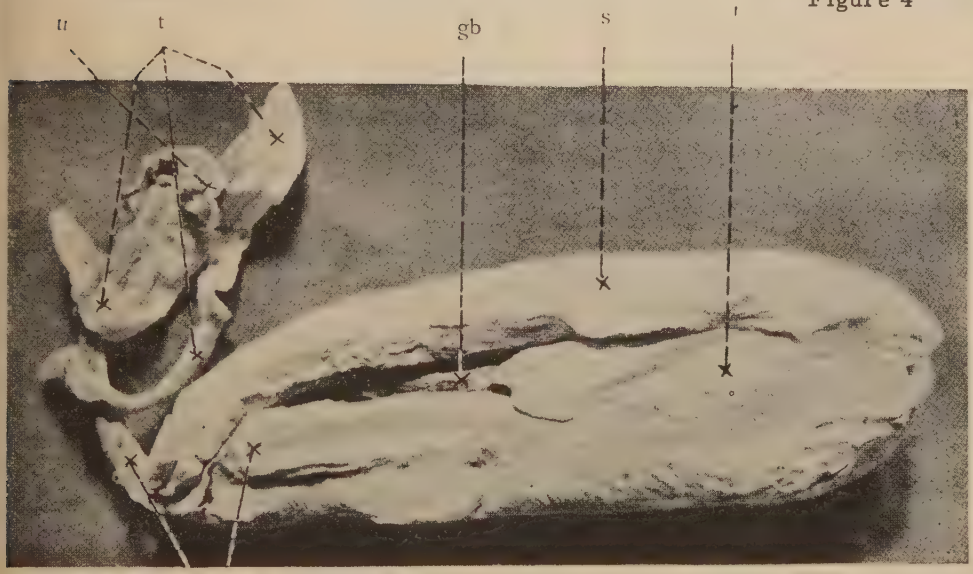


Figure 5

Plate 11.--Figure 1 - ovary (about 1/10 natural size). a - anus; ab - air bladder; af - first anal fin; i - intestine; o - ovary; p - pectoral fin. Figure 2 - ripe egg (spawned egg preserved in alcohol aboard ship X 35). Figure 3 - unripe egg (about times 40), og - oil globule. Figure 4 - mature egg (taken from ovary) X 36, og - oil globule. Figure 5 - testis (about 1/3 life size) gb - gall bladder; i - intestine; l - liver; s - stomach; t - testis; u - ureter

although it is not known how many days are necessary for the maturation of the eggs, is t
is known that in a single sea area over a period as long as 2 months fish with ripe eggs a
with unripe eggs are found mingled together.

As far as the life history of the shortnosed spearfish is concerned, it is thought t
will be comparatively easy to clarify the whole picture by means of large scale fishing ex
ments and marine biological investigations.

III. FISHERIES

It has already been stated that among the fishery products of Taiwan the spearfishe
occupy the first place after the cultivated milkfish. The amounts of spearfish handled at t
fish markets in the various governmental subdivisions in 1933 are as follows:

Table 8.--Amounts of spearfishes handled by governmental subdivisions

Area	Weight	Value
	kin	yen
Taihoku Province	3,916,745	770,171
Shinchiku "	27,686	4,938
Taichū "	347,009	69,797
Tainan "	296,909	57,687
Takao "	2,822,332	453,022
Taitō District	42,968	8,375
Karenkō "	140,395	30,148
Hōko "	-	-
Total	7,594,044	1,394,138

1 kin = 1.32 lbs.

Thus the spearfishes occupy a very important position among Taiwan's fisheries, bu
there appears to have been no particular fishery for these fishes before the Japanese occupa
of the island. Even after the Japanese occupation the development of this fishery has lagged
behind that of the other fisheries.

The spearfish fisheries may be generally divided as follows:

a. Harpoon fishery
b. Longline fishery
c. Other fisheries

A. Harpoon Fishery

(a) History

Before the change of regimes this type of fishery did not exist at all. The beginning o
harpoon fishery in Taiwan dates back to 1923, when fishermen from Oita and Ehime prefectu
came here to start this fishery. Since they had good results, the development proceeded rap
until the fishery reached its present flourishing condition. At present there are actually mor
than 150 vessels engaged in this fishery. When the fishery was first being established, its o
ting area was limited to the vincinity of Suō, but as the number of vessels operating increase
the vessels themselves were built larger the fishing grounds were gradually extended both no
and south until at present the operating radius is from off Taitō on the south to the vicinity of
Hōkasho on the north. However, the fishing grounds shift their position with the season, bei
in the south at the beginning of the fishing season and moving north to the vicinity of Hōkasho

rd the end of the season, and consequently there is also a certain amount of change in the s of the fishery with the season. In the past Suō and Keelung have been the bases, but with completion of a fishing harbor at Shinkō in the Taitō district in 1932 this port came to be as a base for the southern fishing grounds, and at present there are from 20 to 30 boats is type using Shinkō as a base. However, Shinkō is geographically, as well as culturally, inferior to Suō and Keelung as a base, and the amount of fish landed there is far inferior at at the other two ports. In the near future, with the completion of the harbor works at enkō, this port too will naturally be used as a base, and there will be a complete array of s from Shinkō on the south through Karenkō in the middle to Suō and Keelung in the north.

Fishing boats

The fishing boats are of wooden construction with engines of 30-90 HP. At present the t commonly seen type is of 20-30 tons with 40-50 HP and a crew of from 4 or 5 to 10 men. crew is made up of the captain, the engineer, and the fishermen. The fishing boats, ending on their size, have various kinds of large or small platforms built in the bow for the pooner to stand on. The harpooner's platform is built somewhat like a box so as to protect from danger and there is an iron rail (about 2 cm. in diameter) installed alongside him in e of danger. On the larger vessels there is room for two harpooners to stand, one on the t and one on the left, at the same time at the end of the harpooning platform. A lookout is t on the bridge to search the surface of the sea for surfaced spearfishes. Recently simple forms have been built atop the bridges for the convenience of the lookouts on an increasing ber of vessels. In the summer these vessels turn to fishing for coral (see plate 12).

Fishing gear and methods

The main part of the gear is the harpoon. On a pole of oak about 4.5 m. long, an iron three prongs about 8 mm. in diameter is placed and the harpoon points are installed on each hese three tips. The harpoon points are of steel, about 11.5 cm. long, and each one is ched to a wire cable. These wire cables are joined together and go through a ring on the er part of the handle where they join a harpoon line made of 360 strands of No. 20 line. The poon line has about 300 fathoms per basket, and depending on the necessity any number of se baskets can be joined together.

When the lookout sights a surfaced marlin, the boat gives chase at full speed and when eaches an appropriate distance the harpooner throws the harpoon at the fish. If the harpoon nt strikes the fish, it comes loose from the handle and remains within the body of the fish, the handle is recovered by a separate line attached to it. The fish is played on the harpoon e by hand until it is finally hauled into the boat.

ranslator's note: sketch of a complete harpoon and one harpoon point appearing here in the riginal have been omitted from the translation./

Kinds of fish captured

Among the kinds of spearfish taken by the harpoon fishery, the white marlin is most merous followed by the striped marlin, the black marlin, the sailfish, and the broadbill in that der.

As has already been clearly shown in table 7, there is a change in the species composition the catch throughout the season which can be conveniently shown in the following table.

Since tables 7 and 9 also include the catches from fisheries other than the harpoon fishery, e sailfish and black marlin predominate. It is clear, however, that during the season when the rpoon fishery is most active the black marlin is taken in greater numbers than the sailfish.

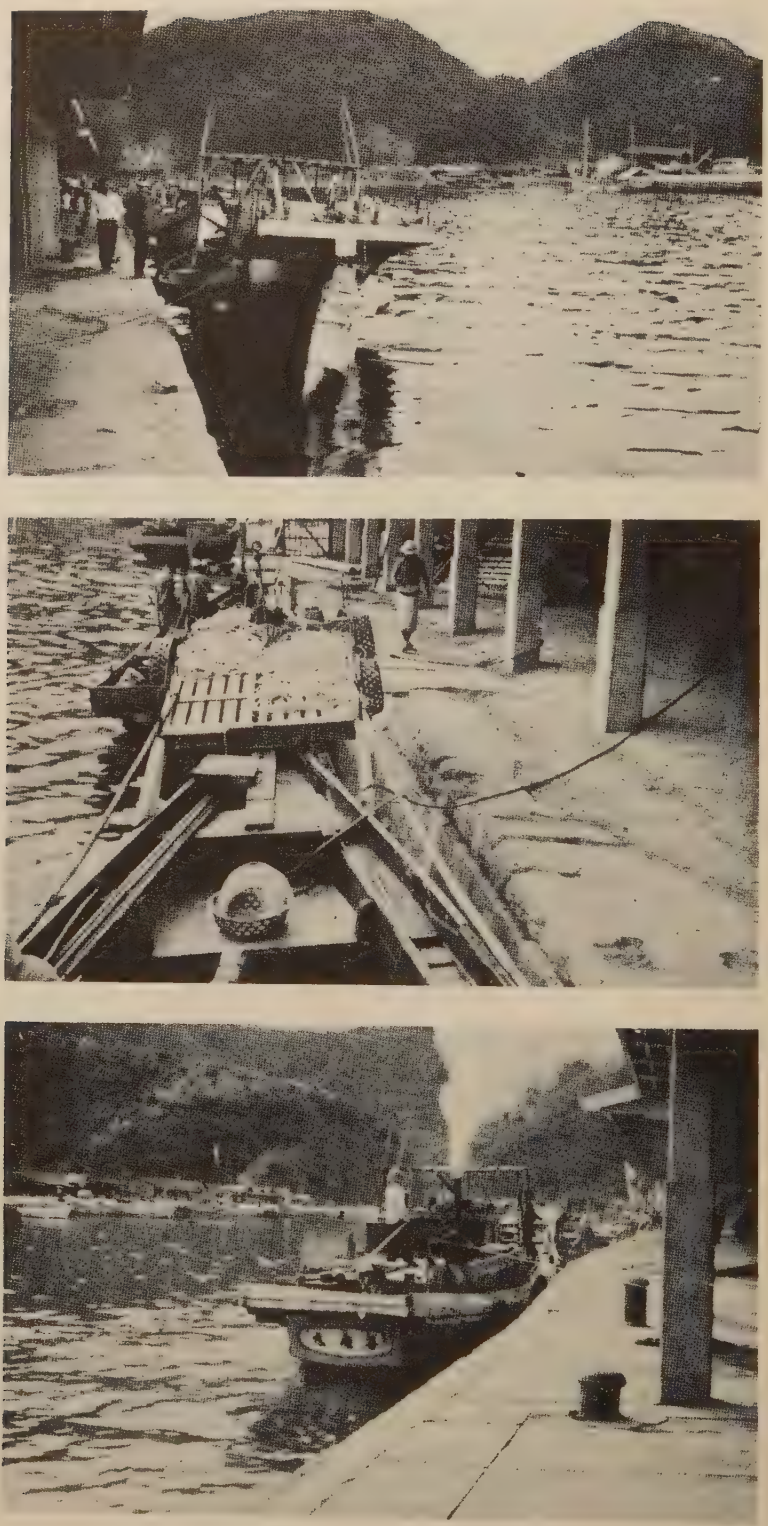


Plate 12.--Three pictures of fishing boats.

Table 9.--Numbers of fish handled by species and months (statistics from the Suō fish market for one year from July 1934 to June 1935)

Year and Month	White marlin	Striped marlin	Black marlin	Sailfish
1934				
July	4	4	9	308
August	11	1	30	253
Sept.	8	5	9	58
Oct.	648	632	49	786
Nov.	1,990	814	86	236
Dec.	1,267	1,030	116	61
1935				
Jan.	1,401	1,488	80	180
Feb.	902	913	258	181
March	1,013	502	250	115
April	462	97	169	97
May	34	5	5	179
June	6	6	3	256
Total	7,748	5,497	1,064	2,710

B. Longline Fishery

Before Taiwan was taken over by the Japanese there was no such fishery as this in the ..nd. A start was made in 1913, when the Government-General began experimenting, and ..reafter the development was swift. The fishery is carried on most actively in Taihoku and ..kao provinces. In 1918 some of the catch was successfully exported to Japan and cultivated ..kfish and mullet began to be used as bait. In 1923, with the completion of the fishing boat ..bor at Suō, a longline fishery based at that harbor was begun. The number of boats based at ..elung, Suō, and Takao increased remarkably and then in 1932, with the completion of the ..hing boat harbor at Shinkō, the fishery also got a foothold there and has continued to develop ..re and more. In the early period of this fishery sailing vessels were used, but now only ..wered vessels are employed. The operating radus was about 20-30 miles off shore at that time, ..at present the fishing grounds in the north have expanded to more than 100 miles from the ..st and the boats based at Takao actually have an operating radius of over 1,000 miles, fishing ..the Sulu Sea and the Celebes Sea. Consequently larger and larger vessels have been built and ..re are already some in the 100-ton class.

The fishing season is approximately half the year, from September to April, and in the ..rth there are more than 250 vessels participating in this fishery, the catch being principally ..earfishes and sharks and having a value of 500,000 yen. Some of these fishing vessels engage ..the coral fishery during the summer.

The total number of longline boats based at Takao is about 200, and their catch has a total ..lue of 1,500,000 yen. Of course this is principally tunas, of which the yellowfin is most numer-..s, the value of the spearfishes being about 600,000 yen.

In the north, that is at Suō, the bait used is largely mackerel. When mackerel are not ..ailable, it appears that milkfish reared in the southern part of the island are used. When the ..ackerel are available, small powered vessels operate mackerel longlines and a part of their ..tch is immediately used on the following day as bait for longline fishing for sharks, spearfishes, ..d tunas. The fishing boats based at Takao formerly used as bait the ginkagami (native name ..oepo") /Mene maculata/, but in recent years pond-cultured milkfish have come to be widely ..ed, and it appears that squid are also sometimes used.

There is some difference in longline gear construction between the north, where s fishes are the principal catch, and the south, where the fishery is primarily for tunas. In th north the gear principally designed to catch spearfishes has mainlines 480 fathoms in leng twelve 8-fathom branch lines at 40-fathom intervals (with 20 fathoms of mainline between last branch line and the end of the basket on each end). The tip of each branch line is prov with a 2-fathom sekiyama, 1 fathom of wire, and on the wire is a round 3.8-inch hook. Ev two branch lines there is a 7-fathom float line, a total of 4 per basket. At the top of each line a 3-foot long paulownia log is attached as a float. The material for the line is 360-thr No. 20 cotton.

In the south, where the fishery is primarily for tunas, the mainline is 390 fathoms with nine 12-fathom branch lines at 40-fathom intervals (with 25 fathoms at the ends so tha are 50 fathoms between the first branch lines of adjacent baskets, the float lines being atta in the middle).

The sekiyama is 4 fathoms long, the wire 2 fathoms, and the hook is similar to that described above. Every three branch lines an 8-fathom float line is attached, so that there 3 per basket. For the floats at the ends of the baskets, glass balls 8 inches in diameter ar the other floats being paulownia billets. The material for the mainline and branch lines is thread No. 10 cotton, while the branch lines are 360-thread No. 20 cotton.

Each of these units is actually stored in a basket. Depending on the size of the vess the amount of gear set varies, but the number carried by a single boat will be 50-100 basket These baskets are fastened together while being set and the floats are attached so that the li hangs down below the surface of the water.

The majority of the boats based at Suō and Keelung are engaged in day fishing, but th large boats sometimes make cruises of about a week's duration. The boats based at Takao r cruises of about 2 weeks ordinarily.

C. Other Fisheries

The harpoon fishery and the longline fishery make up the greater part of the spearfish fisheries, however, other Formosan fisheries which take spearfishes can be cited, such as t trap-net fishery and the trolling fishery. However, compared with the two mentioned earlier their production is extremely small.

(a) Trap-net fishery

From April to the first part of July very dense schools of sōdagatsuwo /Auxis sp./ migrate into the coastal waters of eastern Taiwan. A large number of set-nets are placed ev where along the coast to capture these fish. In these set-nets, besides the Auxis, other misc neous species are caught, including quite a few cybiids and spearfishes. According to the fis statistics for 1934, the amount of spearfishes captured by set-nets for the whole island was 9,776 kin /12,914 lbs./ with a value of 1,639 yen. The catch for the Taitō and Karenkō distr was 9,426 kin /12,442 lbs./ valued at 1,551 yen and the majority of the fish were sailfish.

(b) Trolling fishery and others

Besides the set-net fishery, spearfishes are caught in other miscellaneous fisheries, according to the fishery statistics for 1934 to the amount of about 50,000 kin /66,000 lbs./ wit a value of around 9,000 yen throughout the whole island. It must be stated that this is a very small amount in comparison with the value of the catches of 470,000 yen for the harpoon fishe and 910,000 yen for the longline fishery.

D. Handling and Marketing of the Catch

In the longline and harpoon fisheries based at Keelung, Suō, and Shinkō the fishing grou are very close to the bases, and therefore the majority of the boats leave port before dawn fo

ishing grounds, operate for one day, and return to port in the evening. On these boats ling in particular is done to the catch aboard the vessel, the fish simply being carried on back to the base. However, on the larger harpoon boats the cruises are for about 1 week, on the longline boats based at Takao, where the base and the operating area are widely rated in distance, a rather large number of days is required per cruise. On such fishing s the captured spearfish have their snouts and tail fins cut off and they are wrapped in sul- paper or cloth and stowed in ice before being brought back to the market.

When the fish are landed at the market they are bought by middle men at auction. The rs immediately cut off the heads, gut the fish, cut off the fins, and place the fish in boxes ransport to the various areas of consumption. The consumption of spearfish in Taiwan is t 20 to 30 per cent of the total catch, the rest being exported to Japan or to Manchuria and ea. The prices, of course, fluctuate with the season and economic conditions, but throughout the average price at Keelung was 42 yen per 100 kin. At the end of the year and beginning e year the prices are highest, there being ordinarily a gradual decline in price away from period. Depending on the season there are fluctuations of some extent, but the striped marlin e highest priced, followed by the white marlin, the black marlin, and the sailfish in that r. The broadbill is very cheap. Hardly any shortnosed spearfish are brought in and they no particular name, but those handled at the Suō fishing market are said to be all treated same as the sailfish.

APPENDIX

Table of scientific names and Japanese names:

Scientific names	Japanese names
Istiophorus orientalis	bashōkajiki (baren)
Makaira marlina	shirokajiki (shirokawakajiki)
M. mazara	kurokajiki (kurokawakajiki)
M. mitsukurii	makajiki (akakajiki)
Tetrapturus angustirostris	fūraikajiki
Xiphias gladius	mekajiki (tsun)

Table of Japanese and Formosan names:

Japanese names	Formosan names*
akakajiki (makajiki)	紅肉旗魚
kurokajiki (mazara)	烏皮旗魚
shirokajiki	立翅旗魚
tsun (mekajiki)	丁版舊旗魚
baren (bashōkajiki)	雨傘旗魚
fūraikajiki	none
makajiki (akakajiki)	紅肉旗魚
mazara (kurokajiki)	烏皮旗魚
mekajiki (tsun)	丁版舊旗魚

ranslator's note: As the translator is unable to supply the pronunciation of these names urrent in Formosa and translations of them are not particularly meaningful, they have been iven here in their original form.

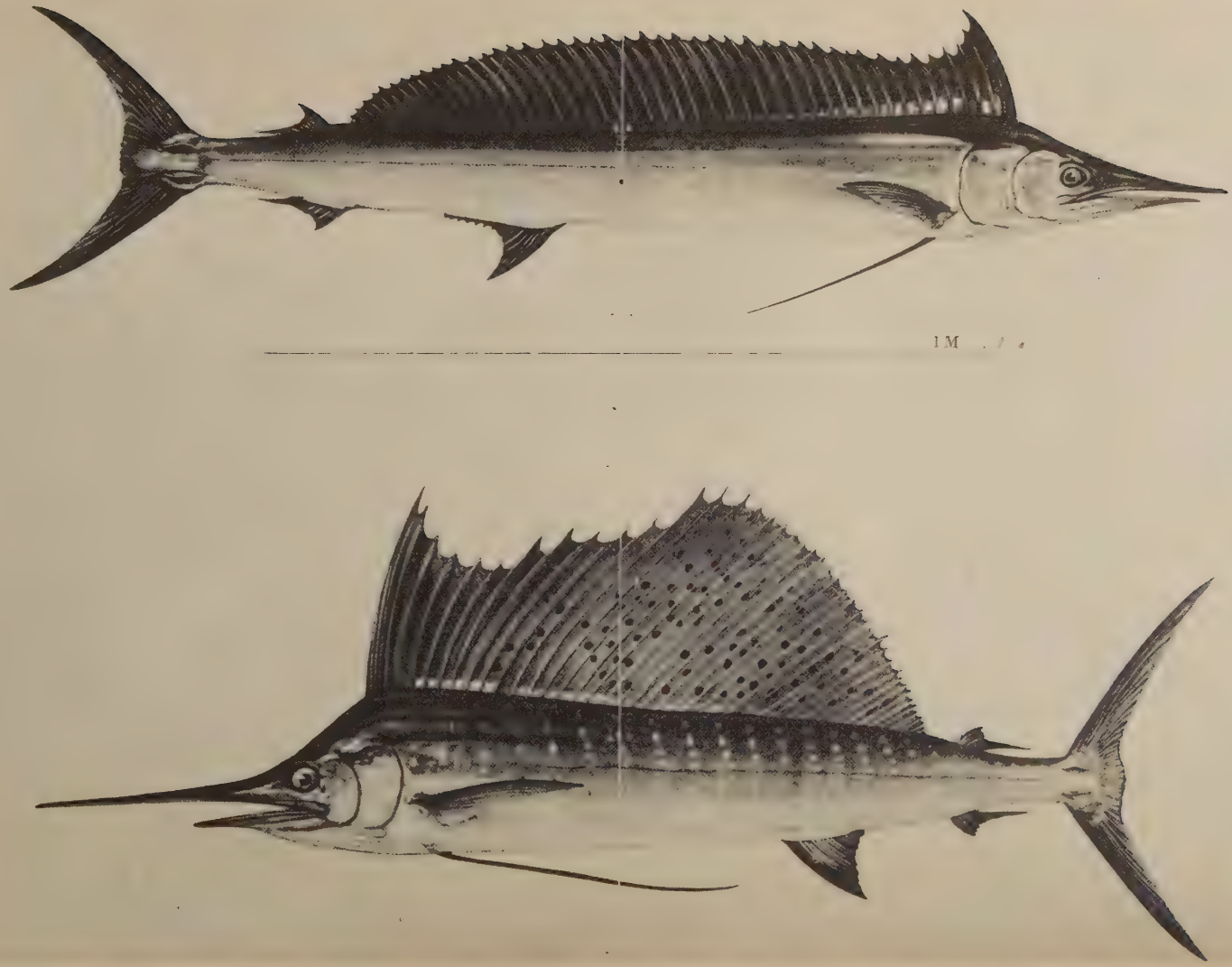


Plate 13.--Figure 1 (upper) shortnosed spearfish; Figure 2 (lower) sailfish.

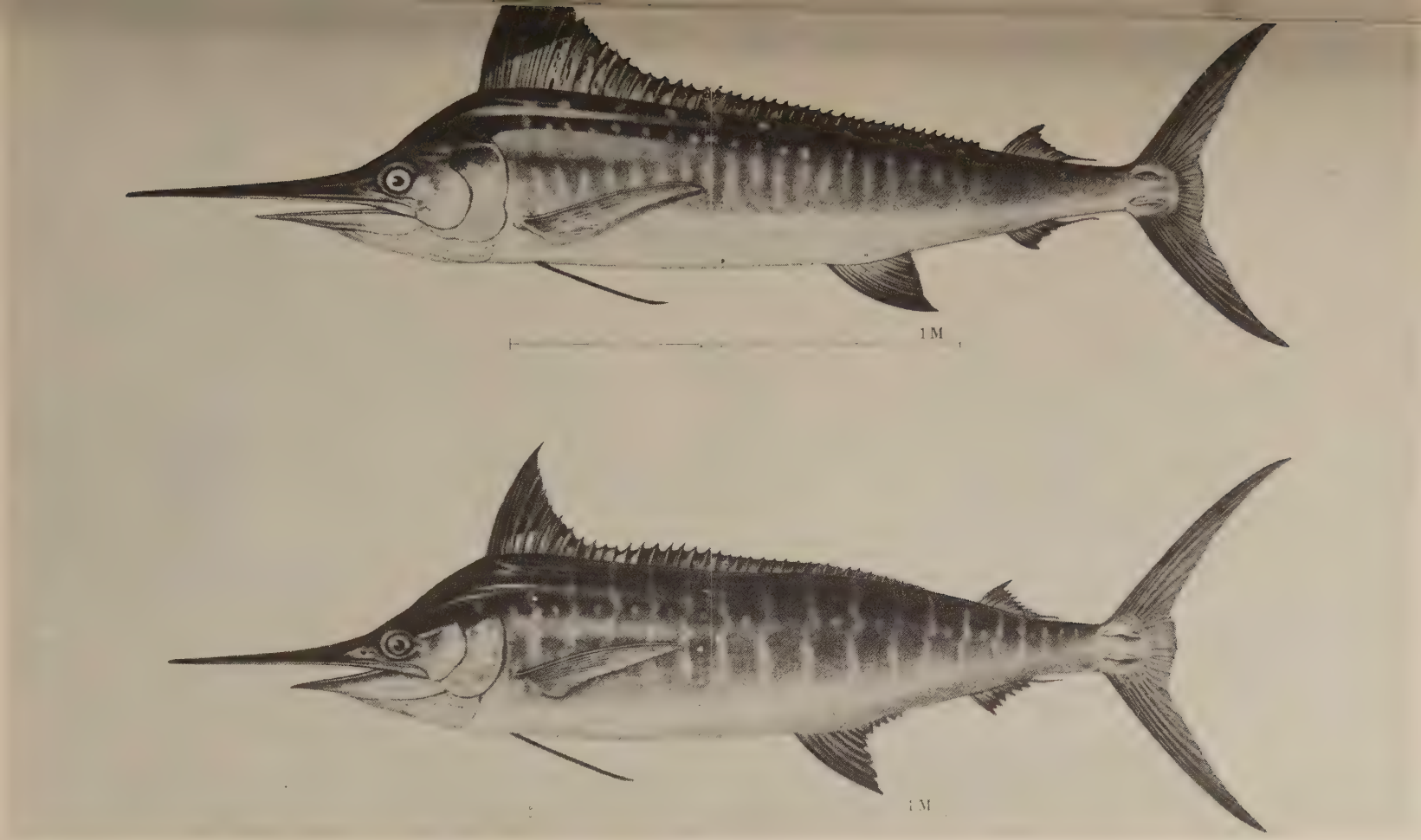


Plate 14.--Figure 1 (upper) striped marlin; Figure 2 (lower) black marlin.

Plate 15.--Figure 1 (upper) white marlin; Figure 2 (lower) broadbill

OXYGEN REQUIREMENTS OF SOME HAWAIIAN TUNA BAITFISH

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FISH AND WILDLIFE SERVICE

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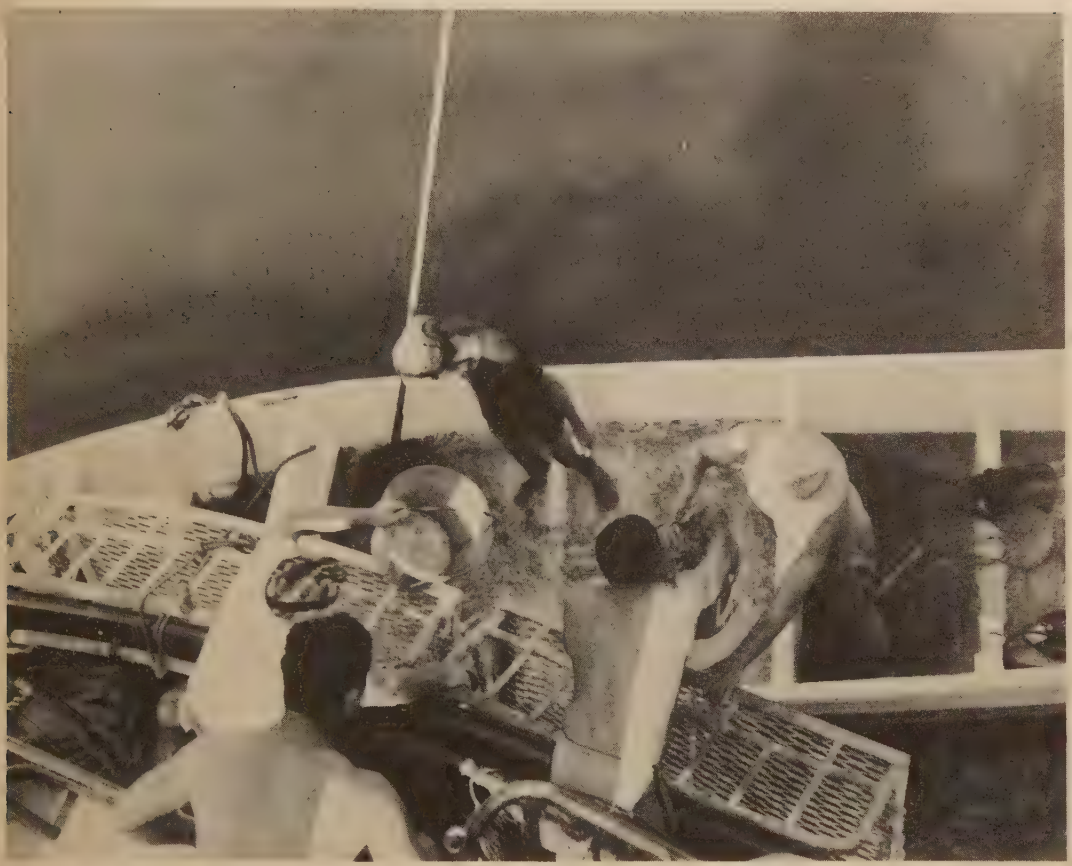

OXYGEN REQUIREMENTS OF SOME HAWAIIAN TUNA BAITFISH

By

Austin Pritchard

Contribution No. 61 from the Hawaii Marine Laboratory

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3099

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The success of livebait fisheries for tuna depends to a large extent on the availability of baitfish. In the Hawaiian fishery for aku (skipjack or striped tuna), Katsuwonus pelamis (Linnaeus), the two species of baitfish most commonly used are the nehu, Stolephorus purpureus Fowler, and the iao, Pranesus insularum (Jordan and Evermann). The nehu, although the less hardy of the two, is the preferred bait. Nehu are generally caught at night by attraction to a light, and both nehu and iao are caught during the day by means of surround nets. Bait is quickly transferred from the nets to livebait wells in the fishing vessels.[1/] The period following the transfer of bait is crucial in livebait fishing, for if water circulation in the live-wells is inadequate and the fish crowd together at the surface or in a corner of the well, considerable mortality may occur. The usual mortality is about 20-30 percent, most of it during the first day, but in some instances it may amount to 50-100 percent.

Heavy bait mortality is probably due to the interaction of several factors. Loss of scales and collisions with the sides of the tank probably lead, directly or indirectly, to the death of many fish. On the other hand, when fish are confined to a limited space, as they are in the livebait wells, the possible depletion of oxygen to levels causing abnormal respiration and suffocation must be considered. This problem of oxygen depletion would be especially acute in those boats (making up the majority of the fleet at present) which employ the method of circulating water through holes in the bottom the well. A few boats possess pumps for circulating water through the live-wells, and may perhaps be less concerned with the problem of oxygen depletion per se. Other questions arise, however, particularly in regard to the effect of different flow rates and various degrees of crowding upon the behavior of the fish. The local annual range of temperature is small, but the possibility of a small but sudden rise or fall in temperature, with its concomitant effects on respiratory metabolism, must be considered.

The object of the present study was to analyze, in the laboratory, the oxygen requirements of the local tuna baitfish in the hope of obtaining basic information which might be of value to livebait fisheries. An investigation of oxygen consumption under various conditions was carried out, emphasis being placed on the effects of temperature, flow rates, various degrees of crowding, and the oxygen concentration of the water. In addition, experiments were designed to determine lethal levels of oxygen for the fish.

The author takes this opportunity to thank Dr. P. B. van Weel for his guidance and constant encouragement throughout this work. Grateful acknowledgement is made to the staff of the Pacific Oceanic Fishery Investigations for advice and technical assistance. Special appreciation is also due Lester Zukeran and Charles Nakamoto of the Hawaii Marine Laboratory for taking a large share of the responsibility for catching and maintaining the stocks.

REVIEW OF THE LITERATURE

An enormous literature exists on respiratory exchange in fish and an extensive review will not be attempted here. A summary of literature relevant to this study will be presented now with mention of individual publications in connection with the appropriate sections of the work. Suehiro's (1951) study of the lethal limits of oxygen for Japanese sardines and anchovies is the only set of observations known to the author on the respiratory metabolism of baitfishes. Besides measuring lethal values of oxygen, Suehiro made several observations on the amount of oxygen consumed by baitfish in live-wells, and emphasized the superior bait-holding capacity of those bait tanks in which water was circulated by pumps.

1/ A good description of the Hawaiian livebait fishery is given by Fred C. June (1951, Commercial Fisheries Review 13(2):1-18).

Note: Financial support for this study came from a U. S. Fish and Wildlife Service fellowship. The material reported forms the greater part of a thesis submitted to the graduate school of the University of Hawaii in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The author at present is a faculty member of the Department of Zoology, Oregon State College, Corvallis, Oregon.

The important factors of temperature and oxygen concentration have received considerable attention from investigators of fish metabolism. At present, the general nature of the effect of temperature and the importance of temperature acclimation seem clearly established (Ege and Krogh 1914; Wells 1935b, c; Sumner and Lanham 1942; Haugaard and Irving 1943), but observed differences among species make it imperative to analyze the influence of temperature on metabolic rate for each species of fish investigated. As regards the effect of oxygen concentration, it would appear that most fish are able to maintain a fairly constant level of metabolism over a wide range in oxygen concentrations (Gaarder 1918; Hall 1929; Keys 1930a, b; Lindroth 1940). There is, however, considerable variation among species as regards the critical concentration, the point at which the rate of oxygen consumption begins to decline. The role of breathing regulation in helping to maintain a constant metabolic rate as the oxygen content falls below normal has been pointed out by several workers (Westerlund 1906; Winterstein 1908; Belding 1929; Meyer 1935; van Dam 1938), but breathing movements and rate of oxygen consumption have rarely been measured at the same time.

The effect of aggregation size on metabolic rate in fish has received comparatively little attention since the initial discovery by Schuett (1933) of a "group effect" in goldfish. Essentially, he found that groups of four fish consumed less oxygen per unit weight than single fish in the same size container. His results received confirmation from Shlaifer (1938) and later Geyer and Mann (1939a, b) reported a "group effect" for the perch (Perca fluviatilis). Large groupings of fish have apparently not been investigated in this regard.

With the notable exception of Hall (1930), almost all the lethal values of oxygen reported in the literature pertain to freshwater fish (Chapman 1939; Moore 1942; Wells 1913; Townsend and Earnest 1940). Individual differences in resistance to low oxygen are pronounced, as indicated by wide range in lethal oxygen values within a species (Wilding 1939). Furthermore, lethal values of oxygen have been shown to vary with temperature and possibly with the size of the fish (Graham 1949; Keys 1931; Moore 1942).

Finally, it is apparent that most of the investigations on fish metabolism in general have been concerned with freshwater species and a need exists for more work on marine forms.

CAPTURE, MAINTENANCE, AND HANDLING OF STOCKS

Practically all the experimental work was performed between 1950 and 1953 at the Hawaii Marine Laboratory, located on Coconut Island in Kaneohe Bay, Oahu. Baitfish, particularly iao, were fairly abundant around the island and could be readily seined in shallow waters. Occasionally fish were attracted to a submerged light and caught in a net lifted from below. Initially stocks were kept in large concrete cisterns some distance away and transferred as needed to aquaria at the laboratory. Later a shallow wooden box (fig. 1) was built for keeping large numbers of fish at the laboratory. Water circulation in this container was efficient and the fish could be easily captured. The fish were fed bread crumbs daily in the early afternoon.

Although both the nehu and iao are delicate fish, the nehu in particular is highly excitable and suffers hemorrhages and loss of scales from rubbing against the sides of the tank. Suehiro (1951) mentions this as one of the principal causes of death of the anchovies (Engraulis japonicus) and sardines (Sardinia melanostica) used for bait in the Japanese tuna fishery. By the end of the summer of 1950 it was obvious that the nehu was unsuitable as an experimental animal and attention henceforth was focused almost entirely on the iao.

Stock mortalities were greatest in the summer months, and large mortalities coincided with severe hot weather, with the water temperature often rising above 29° C. Summer fish, on the whole, behaved more erratically in experiments than winter fish, and seemed particularly susceptible to small increases in temperature. Several summer experiments had to be discarded at the outset because of the obviously abnormal behavior of the fish.

Figure 1.--Holding box for iao at the main laboratory

Two additional factors regarding stock "condition" must be considered. First, fish with injured tails, presumably chewed by other fish, were sometimes seen in the tanks. Their swimming behavior appeared to be normal. Secondly, an ectoparasite was occasionally found attached to the underbelly of the fish. To estimate the incidence of this kind of parasitism, two samples taken near the laboratory were examined. In the first sample, 1 fish out of a total of 95 showed ectoparasites; and in the second sample, only 2 fish out of 390 possessed externally visible parasites. Occasionally, one or two fish with parasites or chewed tails were discovered at the end of an experiment, but the presence of these fish did not appear to change the pattern of the results.

In view of the delicate nature of these fish, considerable care was taken in selecting and handling experimental animals. Fish dissociated from the main school and swimming weakly at the surface were removed as quickly as possible from the stock tanks. In transferring the fish, they were first lifted from the tank in a fine-meshed net, dipped into a beaker, and then poured through a plastic funnel into the experimental container.

MEASUREMENT OF DISSOLVED OXYGEN

The unmodified Winkler procedure was used to measure dissolved oxygen for all the experiments in which the water in the experimental container was continually being renewed. The method is standardized and widely used and, therefore, needs no detailed description. Essentially, the steps outlined by Tully et al. (1950) were followed both in the preparation of reagents and in the collection and preserving of samples. In those experiments where the fish were allowed to use up the dissolved oxygen in sealed jars, the permanganate modification of Winkler's method was employed to avoid possible nitrite error. The procedure followed that outlined by Welch (1948).

Several methods are available for standardizing sodium thiosulfate solutions, and their relative utility has recently been compared (Thompson and Robinson 1939). Potassium bi-iodate, as recommended by Thompson and Robinson, was used as a standard in the present study. This substance is expensive, but is relatively stable and, furthermore, consistent in its results. To standardize the thiosulfate solution, 10 ml. of 0.01 normal bi-iodate was diluted to 50 ml. with sea water, alkaline-iodide and sulfuric acid added in that order, and the released iodine titrated as usual.

METABOLIC RATE UNDER VARIOUS CONDITIONS

Although oxygen uptake is not the only index of activity of an organism, it is correlated quantitatively with rate of metabolism and heat production and is the generally accepted standard measure of metabolic processes. In the present work the terms "metabolic rate", "oxygen consumption", and "oxygen uptake" will all be taken to mean the rate of oxygen consumption, expressed as cc./gram wet weight/hour. The following problems are taken up in this section: (1) the extent of normal fluctuations in rate of oxygen consumption and the presence or absence of

24-hour cycles, (2) the influence of temperature, and (3) the effect of different flow rates, in conjunction with varying quantities of fish, on the metabolic rate. The last problem is of particular interest to the local tuna fishery, since some of the boats are installing pumps capable of regulating the flow of water through the live-wells. To my knowledge, there have been no previous investigations concerned directly with the influence of flow rate on fish metabolism, except ing a short work by Washbourn (1936), who found that the rate of oxygen consumption of trout fry in swift-flowing water was significantly higher than in stagnant water. Wells (1935a) recognized the relation and cautioned that in any series of experiments on fish respiration the flow should be maintained invariable over long periods of time.

The relationship of rate of oxygen consumption to the oxygen concentration of the water itself will be discussed in a separate section.

Apparatus and General Methods

The flowing-water method was used in measuring rate of oxygen consumption, the principal advantage being the continual removal of carbon dioxide and other metabolic products given off by the fish. Essentially, this technique consists in delivering a stream of water to the experimental jar under a constant head of pressure, oxygen samples being taken at the inlet and outlet of the jar. Knowing the weight of the fish and the rate of flow in liters/hour, the rate of oxygen consumption may be readily calculated. Keys (1930b) compared the accuracy of the flowing-water method versus the sealed-jar method and found that, with the latter, few of his determinations could be duplicated to within 15 percent. With the apparatus used in the present study, consecutive determinations (less than 15 minutes apart) never varied more than 15 percent and generally showed closer agreement (see table 4a).

The respiration assembly is pictured diagrammatically in figure 2a. The large battery-jar reservoir (B) and overflow jar (C) allowed a constant head of water to be delivered to the experimental vessel at all times, and simultaneous oxygen samples could be taken by means of the inlet siphon from the reservoir (D) and the connection for outlet samples (F). With the exception of the flow-rate experiments, a 1-gallon wide-mouth jar was used as the experimental vessel. Figure 2b shows the water bath used in the temperature experiments. Immersed in the bath were a thermostatically controlled heating unit, motor driven stirrer, and a coil of copper tubing through which cold water was pumped to lower the temperature in the bath. The entire assembly rested in a Masonite box (not shown in the figure) packed with sawdust. Figure 2c shows the storage jar (about 10 inches in diameter) employed as an experimental container in the flow-rate experiments. A piece of Masonite served as the lid, being connected by threaded brass rods to another piece at the base of the jar. Leakage was prevented by forcing the lid down on a piece of rubber tubing.

In all the experiments oxygen samples were withdrawn in a standard fashion. Sampling bottles were placed simultaneously under (D) and (F) (fig. 2a) and sufficient time was allowed for one and one-half flushings of the bottles.

At the end of an experiment, the fish were weighed to the nearest 0.1 gram on a beam balance after first blotting them on paper towels to remove excess water. Since the validity of wet weight determinations depends on the constancy of the ratio of wet to dry weight, the dry weights of several samples of iao were determined. The samples were dried overnight at 70°-80° F., placed in a dessicator, and daily weighings were taken on a triple beam balance until a constant weight was reached in each of the samples. The percentage of dry weight to wet for each of the samples is shown in table 1 and is seen to vary only slightly. The lengths of all fish used in experiments were determined to the nearest millimeter, from the tip of the snout to the end of the vertebral column.

To determine the extent of oxygen consumption or oxygen production due to plankton in the sea water line, control experiments were run, with a 22-liter carboy as the "dummy" experimental jar. Oxygen samples from inlet and outlet were taken for several hours and a statistical analysis performed on the data (table 2). Although most of the trials showed a very small decrease in oxygen content, the difference was not statistically significant.

Table 1.--Ratios of dry weight to wet weight in iao

Sample No.	Number of fish	A (wet weight)	B (dry weight)	100 B / A
		gm.	gm.	percent
1	10	10.1	2.4	23
2	12	10.6	2.5	24
3	12	11.2	2.8	25
4	16	15.7	3.9	25
5	16	11.4	2.8	24
6	25	21.1	5.3	25
7	15	18.4	4.1	22
8	15	17.2	4.4	26
9	13	16.1	3.8	24
			Average:	24

Table 2.--Dissolved oxygen controls on the flowing-water apparatus used in measuring rate of oxygen consumption

Time	Determination No.	Temperature	Rate of flow	O_2 [1/]	
				Inlet	Outlet
		°C.	l./hr.	cc./l.	cc./l.
9:05 AM	1	23.8	14.52	4.64	4.66
9:45	2	24.0	14.52	4.62	4.62
10:30	3	23.8	14.52	4.64	4.66
11:00	4	23.8	14.52	4.69	4.66
11:35	5	23.8	14.52	4.78	4.72
1:00 PM	6	23.8	14.46	4.82	4.90
1:30	7	24.0	14.40	4.90	4.84
2:45	8	24.0	14.40	4.96	4.93
3:25	9	24.0	14.29	5.04	4.98
4:30	10	23.8	25.71	4.78	4.74
5:00	11	23.8	25.71	4.82	4.78
6:00	12	23.5	10.78	4.91	4.84
7:00	13	23.5	10.59	4.92	4.86

1/ All values are the average of two titrations.

Serial Determinations of Metabolic Rate: 24-Hour Experiments

Procedure.--Preliminary oxygen consumption tests indicated that a more or less consistent level of metabolic activity was reached after 1 to 2 hours in the container. It is not claimed that this represents a "basal" level of metabolism for iao, since the fish are not at complete rest, and furthermore it is obvious from the experiments described below that there is considerable fluctuation from hour to hour in the rate of oxygen uptake. It appears, however, that any great increase in metabolic rate due to the handling of the fish in setting up the experiment is dissipated after 1 to 2 hours.

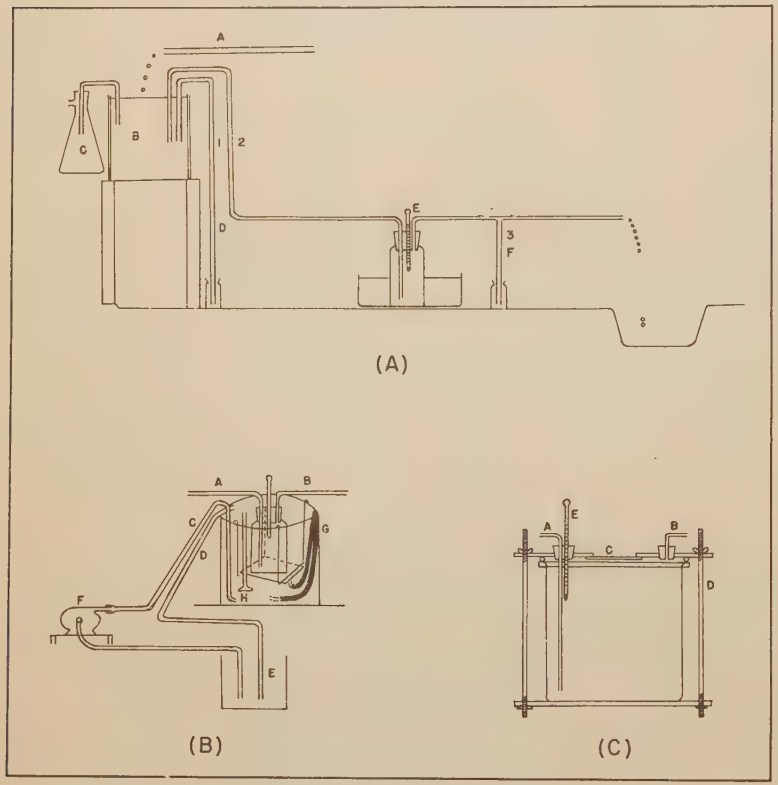

Figure 2a.-- Diagram of the apparatus used for measuring rate of oxygen consumption in iao. A - sea water line; B - reservoir; C - overflow jar; D - siphon for inlet samples; E - thermometer; F - connection for outlet samples. 1, 2, and 3: adjustable hose clamps.

Figure 2b.-- Assembly used for obtaining different temperature levels. A - inlet to experimental container; B - outlet from experimental container; C - inlet to copper coils; D - outlet from copper coils; E - cold bath; F - centrifugal pump; G - heating unit; H - stirring rod.

Figure 2c.-- Diagram of the experimental container used in the flow rate experiments. A - inlet to experimental container; B - outlet from experimental container; C - plastic observation window; D - threaded brass rod; E - thermometer.

In the actual experiments, 10 or more fish were carefully transferred to the jar and water was allowed to flow for 1 hour with the lid removed. The rubber cork with its connections was then inserted and the flow rate was adjusted to 12 liters/hour. Water samples were taken at 1-hour intervals for the first 3 or 4 hours, and approximately at 2-hour intervals thereafter.

Results.--The results of three successful 24-hour experiments, all performed in January and February of 1952, are reported in table 3 and figure 3. Although the data are quite variable, they seem to point to the absence of consistent diurnal cycles in the metabolic rate. In experiments 2 and 3, the rate of oxygen consumption fluctuates irregularly for about 6-8 hours, and then undergoes a slow, but nonetheless noticeable, decline for the remainder of the experiment. In both experiments, there is at the end of the 24 hours a small rise in the metabolic rate for which there is no apparent explanation. These tests, then, show only that there is an irregular, apparently non-cyclic, fluctuation in metabolic rate during the first 24 hours in the jar. Attention is called to the marked rise in oxygen consumption which occurred at

Table 3.--Serial measurements of metabolic rate (cc./gm./hr.) in iáo

Experiment 1

Number of fish: 18
Total weight: 15.9 gm.
Average length: 42 mm.
Range in length: 20-52 mm.

Time of day	Oxygen consumption	Temperature
	cc./gm./hr.	°C.
1215	.358	25.0
1315	.322	25.5
1410	.338	25.5
1800	.283	25.0
2300	.257	23.5
0215	.302	23.3
0640	.244	23.0
0835	.322	23.8
1045	.288	24.6
1150	.285	25.2

Experiment 2

Number of fish: 19
Total weight: 21.1 gm.
Average length: 47 mm.
Range in length: 40-55 mm.

Time of day	Oxygen consumption	Temperature
	cc./gm./hr.	°C.
1200	.288	25.0
1300	.230	25.4
1415	.298	25.0
1510	.313	25.0
1715	.269	25.0
2015	.426	24.5
2300	.263	24.0
0530	.258	23.5
0800	.204	24.0
1100	.209	24.4
1200	.230	24.5

Experiment 3

Number of fish: 20
Total weight: 21.1 gm.
Average length: 46 mm.
Range in length: 38-57 mm.

Time of day	Oxygen consumption	Temperature
	cc./gm./hr.	°C.
1100	.330	25.0
1200	.377	25.0
1300	.313	25.3
1515	.408	25.5
1700	.376	25.3
1915	.392	24.5
2100	.324	24.5
2400	.386	24.0
0300	.380	24.0
0600	.342	24.0
0915	.298	24.0
1115	.329	24.0

2000 hours in experiment 2. The fish might have been disturbed at this time because of frequent switching on and off of lights in adjacent rooms. The pattern for experiment 1 deviates from that of the other two experiments, possibly because of greater fluctuations in the temperature of the water (table 3). The results of this series, at any rate, are to be interpreted cautiously.

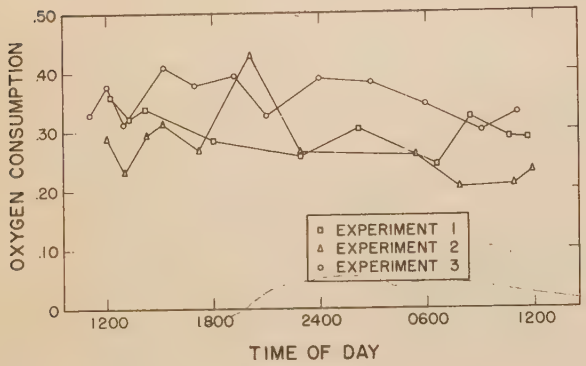

Figure 3.--Rate of oxygen consumption (cc./gm./hr.) in iao over a 24-hour period.

Influence of Temperature on Rate of Oxygen Consumption

Procedure.--With the arrangement shown in figure 2b, it was possible to raise the temperature in the container by approximately 2° intervals and keep it practically constant at any one level. The average variation in temperature was 0.3°C., the maximum variation in any test being 0.5°C. All experiments were begun at 19°C., at least 2 hours being taken to lower the temperature to this value. One set of samples was withdrawn at each temperature level, not less than 1/2 hour after the temperature reached the desired value. Fish used ranged in length from 34-50 mm., the average length of fish in each experiment ranging from 42-48 mm. The tests were run over a 10-day period in October 1951, during which time the temperature in the stock tanks was about 26°C.

Results.--The curve of temperature versus rate of oxygen consumption (fig. 4) resembles those found for other fish (e.g., Ege and Krogh 1914; Wells 1935a; Haugaard and Irving 1943). It rises slowly at first, the slope of the curve being somewhat steeper at the higher temperatures. Over the range in temperatures tested (19°-29°C.) there is an approximately twofold increase in the rate of oxygen consumption. Wells (1935a) has pointed out that small Fundulus show a more pronounced response to temperature changes than larger fish; however, the occasional presence of smaller iao (34-37 mm.) in the present experiments did not appear to alter the pattern of response to temperature. Knowing that the previous temperature history of the fish (acclimatization temperature) can markedly affect subsequent response to temperature changes (Wells 1935b, c; Sumner and Doudoroff 1938; Sumner and Lanham 1942), this factor was controlled as far as possible by running the experiments during one month (October) on fish which had been kept for some time at about 26°C.

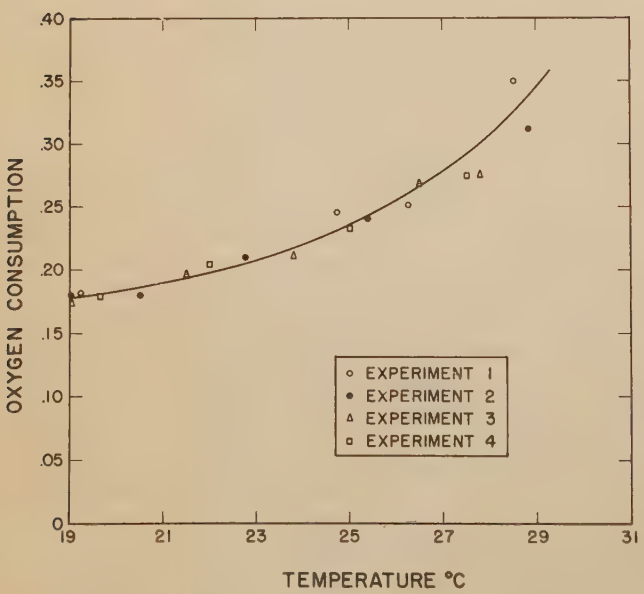

Figure 4.-- Rate of oxygen consumption (cc./gm./hr.) at different temperatures.

Influence of Flow Rate and Numbers of Fish upon the Metabolic Rate

Procedure.--In a typical experiment, the approximate desired number of fish were transferred to the experimental jar (fig. 2c), the flow was adjusted to an intermediate value, and about 1 hour was allowed for the fish to "settle down"

the container. The lid was then inserted and the flow adjusted to the highest value tested. One ur later, two consecutive sets of oxygen samples (in a few instances only one set of samples s taken) were withdrawn, and the flow was then lowered to the next value in the series. Flows nging from 7 to 37 liters/hour were tested in conjunction with aggregations of fish ranging in mber from 20 to 132 or, in terms of concentration per unit volume, 7 to 44 fish per gallon. At latter density the vessel was definitely crowded, but there was no indication of abnormal be- vior, such as changes in schooling pattern, etc. by the fish. The experiments were run in the rning and early afternoon, with an average duration of 4 to 6 hours. All but three tests were rformed in August and September (1951) at temperatures of 27°-28°C. The size of the container itself appeared to keep the temperature from fluctuating and no temperature bath was deemed cessary. Fish of essentially the same size were used in all of the summer experiments, but mewhat larger fish were employed in the few winter tests.

Results.--The complete results are presented in table 4a. Figure 5 is drawn from e summer data and the points represent, where possible, the average of two values at each flow sted. The high values from experiment 4 are not included in the figure. In this experiment, the sh were initially extremely active and their behavior was not considered normal. Referring to gure 5 on the relation between flow rate and rate of oxygen consumption, curve 1 represents ag- regations of 20 to 44 fish, curve 2 aggregations of 75 to 83 fish, and curve 3 applies to a single perinent using 132 fish.

For small aggregations of iao (20-45 fish), the rate of oxygen uptake is seen to crease linearly with increase in flow rate within the limits tested. At the lowest and highest ows, there is remarkable agreement in metabolic rate between the different lots of fish, with ore variability evident at the intermediate flows. For comparable amounts of fish, tested in ovember (experiments 11 and 12), the influence of flow rate upon oxygen consumption is less triking; obviously, however, more experiments would be necessary to establish this point. The ause of this apparent difference in the behavior of summer and winter fish may be the cooler emperatures but attention is also called to the fact that larger fish were used.

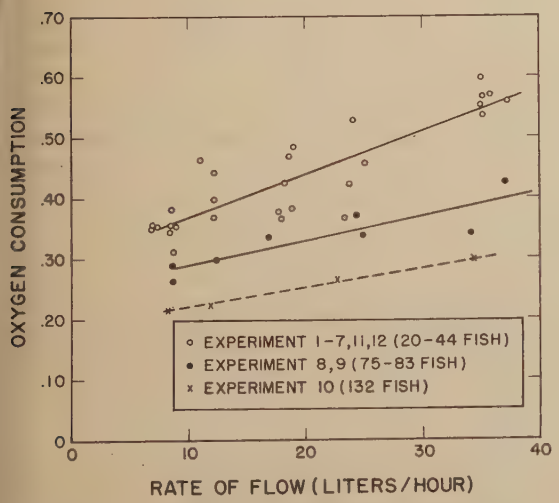

Figure 5.--Rate of oxygen consumption (cc./gm./hr.) in iao at different rates of flow (liters/hour). Regression coefficient for curve 1, .00735; for curve 2, .00412.

With 75 to 83 fish in the container, the relation of flow rate to oxygen consumption is much like that for small aggregations, though the effect appears to be less pronounced. More striking is the fact that the overall rate of oxygen uptake is lower. In experiment 10, where 132 fish were used, the level of oxygen consumption is again lower, but attention is called to the slightly lower temperature at which the experiment was performed.

A field trial, testing the influence of flow rates, was performed in the bait-well of the Territorial Fish and Game vessel Makua. Slightly over 2,000 grams of "mixed" bait (both nehu and iao) was used, giving a density of about 5 fish per gallon, roughly comparable to the minimum density used in the laboratory experiments (7 fish per gallon). The results, plotted in figure 6, show considerable fluctuation but bear some qualitative resemblance, at least, to the laboratory results. The large fluctuations observed may be due primarily to the inadequacies of field sampling.

Table 4a.--Rate of oxygen consumption (cc./gm./hr.) of iao at different rates of flow, in conjunction with varying quantities of fish. Experiments 1-10 were performed in August and September, and experiments 11 and 12 in November

Experiment No.	Number of fish	Total weight	Average length	Average temp.	Range in temp.	Rate of flow (l./hr.)					
						35-37	23-25	17-19	11-12	9	7-8
		gm.	mm.	°C.	°C.						
1	22	20.0	43	26.6	1.0	.588	-	.488	.476	.386	.354
						.606	-	.450	.447	.382	.350
						$\bar{x}$.597	-	.469	.462	.384	.352
2	39	26.5	41	26.9	1.0	.547	-	.424	.387	.348	.356
						.519	-	.424	.402	.351	-
						$\bar{x}$.533	-	.424	.395	.350	.356
3	30	21.7	42	28.0	0.5	.526	-	.343	.360	-	.345
						.571	-	.286	.372	-	.359
						$\bar{x}$.549	-	.315	.366	-	.352
4	26	19.0	42	27.6	0.7	?.893	.487	.481	-	.355	-
						?.964	.554	.481	-	.355	-
						$\bar{x}$.929	.521	.481	-	.355	-
5	44	28.0	41	28.3	0.5	.554	.465	.360	.428	Temp. rising, fish excited	
						.579	.438	.367	.460		
						$\bar{x}$.567	.452	.364	.444		
6	20	15.2	42	27.3	0.8	.533	.383	.400	-	.358	-
						.580	.353	.362	-	.335	-
						$\bar{x}$.557	.368	.381	-	.347	-
7	28	21.0	42	27.0	0.4	.543	.429	.374	-	.313	-
						.578	.417	.381	-	.309	-
						$\bar{x}$.561	.423	.378	-	.311	-
8	75	55.2	41	28.4	0.0	.426	.367	-	.299	.291	-
						.419	.372	-	.298	.290	-
						$\bar{x}$.422	.370	-	.298	.290	-
9	83	51.4	39	28.4	0.1	.333	.338	.331	-	.263	-
						.346	.338	.334	-	-	-
						$\bar{x}$.340	.338	.332	-	.263	-
10	132	116.3	43	26.1	0.2	.289	.263	-	.220	.215	-
						.295	-	-	-	-	-
						$\bar{x}$.292	.263	-	.220	.215	-
11	30	34.5	47	24.8	0.1	.285	.300	-	.246	.241	-
						.285	-	-	-	-	-
						$\bar{x}$.285	.300	-	.246	.241	-
12	35	44.4	48	24.3	0.7	.242	.218	-	.197	.183	-
						.220	-	-	-	-	-
						$\bar{x}$.231	.218	-	.197	.183	-

Discussion

A striking feature of the serial observations of rate of oxygen consumption (table 3) the great variability from hour to hour. Such fluctuations are apparently not uncommon, however, having been observed by several workers (Chapman 1939; Clausen 1936; Shlaifer 1939; Wells 1935a). The following statement of Wells (1935a) is perhaps apropos: "Duplication of results with the same animals at two different times is not a measure of the efficiency of the apparatus, nor is failure to duplicate results a reflection upon the method." Krogh (1916) mentions that the respiratory exchange in a normal animal may vary 100 percent or more. Over the 24-hour period during which serial observations were made, no consistent rhythms in metabolic rate were evident. Daily cycles in metabolic rate have been claimed for a few freshwater fish (Clausen 1936; Fuya and Kimata 1938; Higginbotham 1947) but have not received extensive confirmation.

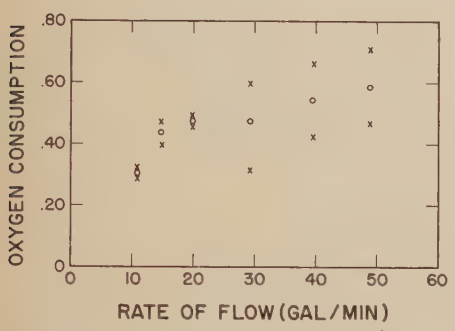

Figure 6.--Results of a field experiment testing the influence of flow rate (gal./min.) on rate of oxygen consumption (cc./gm./hr.). Open circles represent the average of two determinations of oxygen consumption (represented by crosses) at each flow.

The temperature-oxygen consumption curve (fig. 4) in general resembles those for other fish but must, of course, be interpreted entirely upon its own merits, particularly since a relatively narrow temperature range was studied. The curve may be said to represent an experimentally determined relationship of temperature to rate of oxygen consumption in iao ranging in size from 34 to 50 mm. for the temperature interval 19°-29°C. In view of the apparently valid arguments of Ege and Krogh (1914) and Wells (1935a) against the unrestricted use of Van't Hoff's Q_{10} and the Arrehenius relation, no attempt was made to calculate either Q_{10} values or "thermal increments." Ege and Krogh, for example, found that Q_{10} varied from 9.8 at 0°-5°C. to 2.2 at 23°-28°C. in the goldfish.

At the higher temperatures in the range tested, the effect of temperature upon metabolic rate appears somewhat more pronounced. Since the local fishery is conducted almost entirely during the summer and early fall, when water temperatures often rise to 27°-28°C. and higher, it may be advisable to watch for sudden changes in the water temperature of the live-wells. Even a small rise in temperature might considerably increase the activity and consequently the rate of oxygen consumption of the fish.

That the rate of oxygen consumption should rise with increase in rate of flow is perhaps not surprising, inasmuch as the fish would presumably exert more energy in swimming as the current of water through the jar increases in intensity. In curve 1 (fig. 5), representing small aggregations of fish and based on the most extensive collection of data, oxygen consumption increases linearly with flow rate over the range from 7 to 37 liters/hour. The points appear less scattered at the extreme flow values. This may be a chance variation or the fish, for some reason, may exhibit a uniform metabolic response to the environment at the extreme flow rates. This explanation is easier to accept in the case of the high flow values (35-37 liters/hour), where the fish might all be exerting approximately the same amount of energy in maintaining their position against the strong current.

When larger numbers of fish are used (curve 2, fig. 5), the overall level of metabolism is lower. An analysis of covariance (tables 4b and 4c) on the data making up curves 1 and 2 yields the following statistical conclusions: 1) the difference between the mean values for metabolic rate, adjusted to a common flow value, of group 1 (20-45 fish, adjusted mean 0.431 cc./gm./hr.) and group 2 (75-83 fish, adjusted mean 0.320 cc./gm./hr.) is highly significant ($P < 0.01$), indicating

Table 4b.--Analysis of covariance and test of significance of adjusted mean oxygen consumption values for group 1 (20-45 fish) and group 2 (75-83 fish)

Source of variation	Degrees of freedom	Errors of estimate		
		Sum of squares	Degrees of freedom	Mean square
Total	36	0.145	35	-
Groups	1	-	-	-
Within groups (error)	35	0.069	34	0.0020
For testing significance of adjusted means	-	0.076	1	0.076 **

**Significant at 1-percent level ($P < 0.01$).

Table 4c.--Analysis of errors of estimate from the average regression within groups

Source of variation	Degrees of freedom	Errors of estimate	
		Sum of squares	Mean square
Deviations from average (error) regression within groups, table 4b	34	0.069	-
Deviations from individual groups regressions	33	0.063	0.0019
Differences among group regressions	1	0.006	0.006

that the drop in oxygen consumption is probably a real one; and 2) the difference between the slopes of the two curves is not significant (table 4c), indicating that the effect of flow rate on oxygen consumption is similar regardless of the numbers of fish tested.

The drop in metabolic rate with larger groups of fish deserves further discussion. Schuett (1933) and Shlaifer (1938) both point out that 2 to 4 goldfish in a container consume significantly less oxygen per unit weight than single fish. A similar "group effect" has been observed by Geyer and Mann (1939a, b) in Perca fluviatilis. All these authors find that the effect disappears when the size of the container is increased in proportion to the increase in numbers of fish. The present data are inadequate to justify anything but tentative conclusions. The decrease in metabolic activity is perhaps due to changing intensity of motion caused by the reduction in space available per fish. No evidence is available, however, attesting to the possible influence on the

metabolic rate of accumulated excretory products and other gases, particularly when large numbers of fish are used. This aspect should be investigated further. Geyer and Mann (1939a) are of the opinion that a decrease in oxygen concentration with greater numbers of fish is responsible for the "group effect." This factor can probably be neglected in the present work since, as will be pointed out in the next section, oxygen consumption in the iao is independent of concentration down to at least 2.5 cc./l. In the flow-rate experiments, the oxygen concentration of the outlet samples in no case fell below 2.5 cc./l.

It is of interest to evaluate these laboratory findings in terms of the problems involved in keeping bait alive in fishing vessels. The lowering of metabolic rate with large numbers of fish might be construed to mean that increasing the number of fish in a live-well leads to more efficient maintenance. This may be true, but more data are necessary to substantiate such a view. Furthermore, if too many fish are present, the oxygen content of the water obviously may be reduced to near the lethal value, which, as will be seen shortly, is about 1.0 cc./l. for iao. For nehu, the preferred baitfish, the limited data available indicate a lethal value of about 2.0 cc./l. (table 7). Those boats having pumps could handle more fish by increasing the flow rate through the live-wells, but this in itself causes an increase in activity and oxygen consumption (fig. 5). In order to arrive at the best combination of flow rates and aggregation size the present laboratory experiments should be followed up by field tests, possibly using the same flow rates and densities of fish.

METABOLIC REGULATION IN THE IAO

In summarizing the literature pertaining to the relationship between rate of oxygen consumption and the dissolved oxygen content of the water, it is apparent that some fish are markedly affected by changes in external oxygen while others are not. Gaarder (1918) found a very slight dependence of oxygen consumption on oxygen concentration in the carp. Powers and Shipe (1928) claim that for herring, coho salmon, and viviparous perch a decrease in the amount of dissolved oxygen caused a proportional decrease in the rate of oxygen consumption. According to Hall (1929), the degree of metabolic regulation depends on whether the fish is an active or sluggish species, the former showing metabolic independence and the latter complete dependence on the oxygen concentration of the medium. In any event, small changes from the normal oxygen content of the water probably do not affect oxygen uptake in most fish (Keys 1930a; Wells 1935a; Lindroth 1940; Fry and Hart 1948), but an oxygen level is eventually attained below which metabolic adjustment fails and the rate of oxygen uptake begins to decrease. This "critical level" varies with species and with temperature (Lindroth 1940; Fry and Hart 1948; Graham 1949).

One means by which fish accomplish metabolic regulation is an increase in the frequency of breathing movements. This compensates for the fall in oxygen concentration by permitting more water per unit time to flow past the gill surfaces. Several workers (Westerlund 1906; Winterstein 1908; Wells 1913; Gardner and King 1922; Belding 1929; Wilding 1939) have incidentally observed an increase in the rate of opercular movement, to a greater or lesser degree, with a decrease in the oxygen content of the water. On the other hand, there are few works in which both the rate of oxygen consumption and breathing movements are analyzed and their interrelations discussed. Notable exceptions are papers by Meyer (1935), who worked with Uranoscopus scaber, and van Dam (1938), who worked on eel and trout. Both workers determined not only breathing rate, but breathing depth and ventilation volume in relation to oxygen concentration. Van Dam found that the eel (Anguilla vulgaris) showed much better metabolic regulation than the trout (Salmo shasta).

The above discussion points to the importance of determining the degree of metabolic regulation in any fish whose oxygen relations are being investigated. In this section the relationship of metabolic rate to oxygen concentration is analyzed, and to supplement these data the rate of opercular beat is determined at various oxygen values.

Apparatus

To introduce water of different oxygen concentrations, several modifications in the basic experimental assembly were necessary. Figure 7 shows the modified assembly set up for experiments on breathing movements. When the apparatus was used to determine rate of oxygen consumption, a wide-mouth gallon jar was substituted for the glass tube shown suspended in the water bath. The carboy on the left contained water low in oxygen, obtained by bubbling through nitrogen gas, and the one on the right contained normal sea water. Water from both carboys was joined by a "Y" tube into a single flow entering the overflow flask. Oxygen samples were taken in the manner described earlier, with the exception that inlet samples were siphoned from the overflow flask. Control tests indicated only negligible variation in dissolved oxygen content between carboy, overflow flask, and the outlet of the experimental chamber.

Relation between Dissolved Oxygen Concentration and the Rate of Oxygen Consumption of the Iao

Procedure.--Since the supply of low-oxygen water from the carboy was limited, the plan was to test several lots of fish, each at a different oxygen level, from 7 to 14 fish being used in each experiment. After the fish were in the container, normal sea water was circulated through the jar for 1 hour. Two consecutive sets of oxygen samples were then taken from which the average rate of oxygen consumption in normal sea water, i.e., the "control" value, was calculated. The normal sea water line was then pinched off and oxygen-poor water was permitted to circulate through the system. After 30 minutes, a set of oxygen samples was taken and the metabolic rate at the new oxygen level was determined.

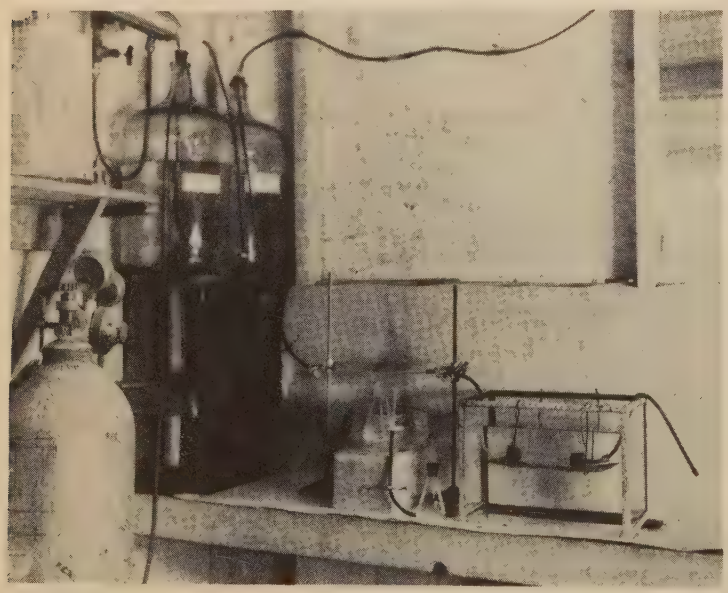

Figure 7.--Apparatus used in measuring oxygen consumption and breathing rate at different oxygen concentrations. The apparatus is shown assembled for breathing rate experiments. Detailed description in text.

The experiments were all performed during morning hours at temperatures generally between 24° and 25°C. A fairly wide range of sizes was employed, the average length of fish in each test ranging from 37 to 49 mm.

Results.--The relationship between oxygen consumption and oxygen concentration (fig. 8) shows that the rate of oxygen uptake fluctuates about a constant level down to low values of oxygen but eventually starts to fall, the decline becoming more rapid as the lethal value of oxygen is approached. Complete data are reported in table 5. Unfortunately, few points are available in the region where the decline in oxygen consumption begins and it is difficult to establish anything like a definite "critical" level of oxygen. At best, it can be stated that the critical level lies between 1.5 and 2.5 cc./l. Some of the scattering of points, particularly in the first part of the curve, may be attributed in part to the rather large range of sizes used. On the other hand, tests in which a great many small fish were used did not indicate, on the whole, a greater or lesser decrease in oxygen consumption compared with tests in which many large fish were used. (Compare, for example, experiments 7 and 14, table 5.) Since the experiments were performed over a fairly narrow range of temperatures, it appears unlikely that the critical level would be shifted due to differences in temperature between tests.

Table 5.--Rate of oxygen consumption (cc./gm./hr.) at various oxygen concentrations

Experiment No.	Total weight of fish used	Range in length	Average length	Temperature	Average control O_2 value	Rate of oxygen consumption (control)	Average experimental O_2 value	Rate of oxygen consumption (experimental)	Decrease in consumption from control
	gm.	cm.	cm.	°C.	cc./l.	cc./gm./hr.	cc./l.	cc./gm./hr.	cc./gm./hr.
1	8.1	44-57	49	23.5	4.21	.330	1.15	.079	.251
2	7.0	41-54	44	23.6	4.13	.428	1.09	.166	.262
3	6.8	44-56	48	24.0	4.14	.354	1.14	.107	.247
4	9.1	41-51	46	24.8	4.06	.417	1.25	.204	.213
5	10.6	42-59	47	24.4	3.93	.374	3.42	.304	.070
6	10.0	36-51	45	25.0	3.95	.522	1.12	.209	.313
7	12.4	36-52	44	25.0	3.82	.506	2.66	.369	.137
8	9.6	36-55	44	25.0	3.96	.416	2.22	.292	.124
9	9.0	35-52	46	25.2	4.12	.446	3.02	.394	.054
10	9.9	38-56	46	24.2	4.08	.448	3.05	.358	.090
11	8.2	30-51	46	24.8	3.91	.423	3.86	.346	.077
12	8.0	36-50	45	25.6	4.09	.437	3.90	.393	.044
13	9.7	43-51	48	24.0	4.07	.353	1.14	.144	.209
14	6.1	32-49	39	25.5	3.86	.484	1.12	.161	.323
15	5.3	33-44	39	26.0	3.82	.478	1.44	.308	.170
16	5.6	34-45	37	25.8	4.09	.420	2.71	.328	.092
17	7.2	38-52	39	26.8	5.39	.417	3.10	.417	.000
18	6.9	35-46	41	25.0	3.86	.448	1.58	.258	.190
19	9.3	33-52	41	24.5	3.88	.347	1.84	.261	.086

Frequency of Opercular Movements in Iao at Different Oxygen Concentrations

Procedure.--To obtain accurate gill movement counts, it was necessary to immobi-ze the fish, which was done by placing it in a clay mount on a microscope slide with only the ead and gill cover protruding. With practice in the technique, handling could be reduced to a inimum. The immobilized fish was placed in a finger bowl of sea water and, if it did not work ee and if it assumed a regular opercular beat, it was quickly transferred to the glass tube im-ersed in the water bath. Normal sea water was allowed to flow through the tube for about 30 inutes before counts were taken. In these experiments it was possible to test an individual fish more than one oxygen level, the different levels being obtained by mixing appropriate amounts f water from the two carboys. Five determinations of the time required for 50 beats (from which e beats/minute was calculated) were taken at each oxygen value.

The reliability of the method was tested by taking counts in normal sea water over a 0-minute period (the maximum duration of any experiment) on two fish. The results indicated ttle fluctuation in normal opercular rhythm. For each fish 15 separate counts were taken, the eans and standard deviations being 215 ± 4.2 (fish 1) and 213 ± 3.7 (fish 2).

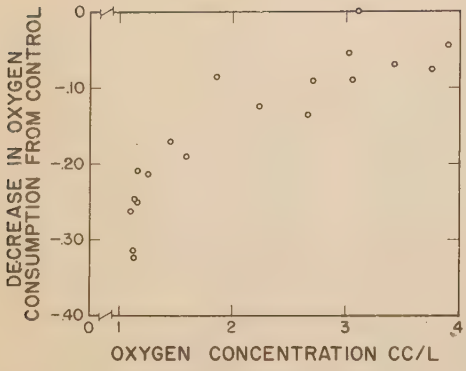

Figure 8.--Change in rate of oxygen consumption (cc./gm./hr.) with a decrease in the oxygen content of the water. Ordinate represents the decrease in rate of oxygen consumption from control values.

The experiments were performed in February of 1952 and 1953, at temperatures of 23°-24°C. (average 23.9°C.). Fish used ranged in length from 39 to 62 mm. and in weight from 0.56 to 2.46 gm., weight being taken to the nearest 0.01 gm. on a Roller-Smith torsion balance after 1 week's preservation in 10-percent formalin.

Results.--From the eye-fitted curve (fig. 9) it is seen that as the oxygen content of the water falls, the respiratory rate rises, slowly at first, then more rapidly, to a peak beyond which it slowly decreases. The maximum breathing rate is attained probably somewhere between 2.0 and 2.5 cc./l.--the peak in the curve is not well defined, principally because of the very gradual subsequent decrease in breathing rate. The points are widely scattered in the first part of the curve and this is reflected in the behavior of the fish. As the oxygen concentration is lowered the fish at first show some agitation and occasional irregular breathing. Later, at the very low oxygen values, breathing is slower and more regular. No quantitative measurements of breathing-depth were made, but the fish were observed to breathe deeper, as well as faster, as the oxygen content was lowered. Deep breathing continued, in several cases, after breathing frequency began to diminish.

Discussion

Comparison of the relationship of oxygen consumption (fig. 8) and opercular rhythm (fig. 9) to the oxygen content of the water is experimentally difficult for at least two reasons. For one thing, it was necessary to use different techniques in each series of tests. In the experiments on oxygen consumption each group of fish could be tested at only one oxygen level, whereas in the breathing rate experiments a fish could be run through a whole series of oxygen values. Furthermore, the points are somewhat scattered in both cases, especially at the higher oxygen concentrations, and it is difficult to determine precise oxygen values below which rate of oxygen consumption and breathing rate decline. With these precautions in mind, it is still perhaps safe to say that both breathing rate and oxygen consumption begin to decrease at approximately the same level of oxygen, somewhere between 1.5 and 2.5 cc./l., the implication being that the fall in breathing rate contributes, in part at least, to the fall in oxygen consumption. From the standpoint of the livebait fishery, a "danger" point might be placed at 2.5 cc./l. If the oxygen content of the water in the live-wells falls much below this value, the fish will more than likely not be getting sufficient oxygen to maintain normal metabolism.

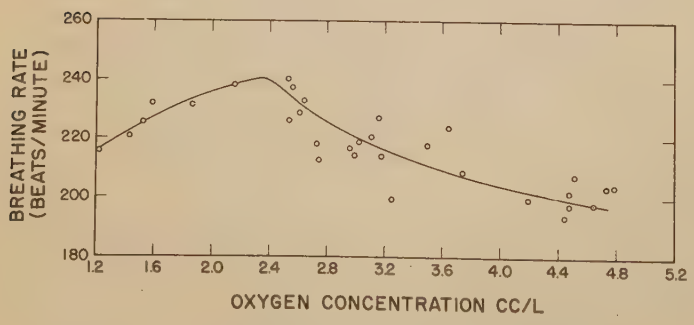

Figure 9.--Breathing rates (beats/minute) at different oxygen concentrations.

LETHAL VALUES OF OXYGEN

A major problem in the confinement of baitfish is the possible depletion of oxygen to a level below that tolerated by the fish. Suehiro (1951) found that newly introduced "wild" bait congregated densely at the surface, and a localized depletion of oxygen to below the lethal value occurred, regardless of an increase in the

nount of water circulated through the tank. Information on lethal values of oxygen is widely attered through the literature and there are few extensive experimental investigations of the bject. In view of these considerations, it was thought worthwhile to determine the lethal value oxygen for the local species of baitfish. Both individual fish and groups of 10 to 15 fish were phyxiated in closed containers. In addition, the effect of temperature on the lethal value of oxyn was determined, single fish being employed for these tests. Complete cessation of all movents, breathing or otherwise, was taken as indicating the death of the fish, the validity of this iterion being evidenced by the fact that no recoveries were obtained upon return to normal sea ter.

With the exception of the first summer's experiments, all oxygen samples were anazed by the Rideal-Stewart modification of Winkler's procedure. A comparison between the modid and unmodified methods is reported in table 6. The oxygen samples were siphoned off siultaneously from large, sealed Erlenmeyer flasks in which fish had been using up the dissolved ygen for some time. The mean difference in the values obtained by the two methods is not sigficant (P = 0.08), but the discrepancy in some of the trials is pronounced; to be safe, therefore, was decided to use the Rideal-Stewart procedure.

Table 6.--A comparison of the Rideal-Stewart and unmodified Winkler procedures for determining the dissolved oxygen content of water in which fish have extensively respired

Experiment No.	Number of fish	Oxygen at end of experiment (cc./l.)		
		Rideal-Stewart	Unmodified	Difference
1	5	2.40	2.50	-0.10
2	6	2.48	2.46	0.02
3	7	1.45	1.38	0.07
4	4	3.08	3.06	0.02
5	4	1.38	1.08	0.30
6	4	2.46	2.48	-0.02
7	3	1.02	0.94	0.08
8	3	1.30	1.16	0.14
9	2	1.28	1.20	0.08
10	3	1.32	1.24	0.08
11	4	1.10	1.12	-0.02

Mean = 0.059

Standard Error of the Mean = 0.031

"t" = 1.90

P = 0.08

Lethal Values of Oxygen for Nehu and Iao: Experiments Using Single Fish

Procedure.--For most of these tests Florence flasks of about 540 ml. capacity were employed as experimental containers. Occasionally, depending on the size of fish used, larger or smaller flasks were necessary. The flasks were surrounded by white cloth to prevent the fish from becoming unduly excited, and a small piece of screening was placed in the neck to keep the fish from entering this portion of the flask.

After the fish was transferred to it, the flask was filled, stoppered, and immersed to its neck in a water bath. Initial oxygen samples were obtained from flasks immersed in the water bath but containing no fish. After all movement of the fish in the experimental jar had ceased, an oxygen sample was quickly siphoned off, the water being allowed to circulate through the bottle for a few seconds after it was filled. In some of the earlier experiments a 50-ml. sample was then taken for pH determination, leaving about 50-70 ml. in the flask. The length of the fish, from the tip of the snout to the end of the vertebral column, was taken to the nearest millimeter, and with the exception of some of the earlier experiments, the fish were preserved in 10-percent formalin to be weighed later on a Roller-Smith torsion balance.

As a check on the possibility of errors due to absorption of oxygen during siphoning, water samples of low oxygen content were siphoned off from two flasks, one with a layer of mineral oil and the other without the layer. The difference in amount of dissolved oxygen between these samples was within the error of the Winkler procedure.

The experiments on iao were divided into two groups, a summer series and a winter series, reported respectively in tables 8a and 8b. Eleven experiments were performed with nehu, all in the late spring and summer of 1950, and these are reported in table 7.

Results.--Considerable variability was evident in the results, as might be expected in collecting data on individuals. The mean and standard deviation of all the summer lethal values for iao (table 8a) was 1.10 ± 0.22 cc./l. and that of the winter values 0.96 ± 0.18 cc./l., with mean temperatures of $25.6 \pm 0.9^{\circ}$C. and $21.9 \pm 0.6^{\circ}$C. respectively. The difference between these mean values, when tested statistically by analysis of variance (table 8c), was found to be significant at the $P = 0.05$ level. The mean lethal value for nehu was 2.02 cc./l. with a standard deviation of 0.35 cc./l., much larger than that for either series on iao. The great variability of the nehu data was probably a consequence of the fish's behavior when confined to the experimental flask. In contrast to iao, nehu generally remained greatly agitated throughout the experiment and some undoubtedly became injured, thus causing an abnormally high lethal value of oxygen.

Weights were not available for all the fish used, but the data on hand show no significant relationship between weight of fish and the lethal value of oxygen. Regression lines for both summer and winter data did not differ significantly from zero ($P = 0.1$ in both cases). At best, a slight trend towards greater resistance to oxygen deficiency in the larger fish was indicated.

It seems fairly certain that the death of the fish in these tests was due to lack of sufficient oxygen and was not affected by a lowering of the pH during the course of the experiment. Hydrogen ion concentration was measured at the end of the earlier experiments and was never less than 7.80, averaging 7.87. The water in the stock tanks often showed pH values of this magnitude.

Some evidence is available (experiments 16, 17, and 18 of the winter series) to indicate that lethal values of oxygen are about the same regardless of the initial oxygen content of the water. This point, however, needs further investigating.

Table 7.--Lethal values of oxygen for nehu

Date	Experiment No.	Temperature	Duration of experiment	O_2 (cc./l.)		Volume of jar	Length of fish
				Initial	Final		
		°C.				cc.	mm.
3-9-50	*1	22.9	1hr40min	5.04	2.54	1070	-
3-17-50	*2	24.7	1hr45min	4.95	2.42	"	-
3-18-50	*3	25.0	2hr15min	5.36	1.87	"	-
3-21-50	*4	24.8	1hr47min	4.90	2.41	535	-
4-22-50	*5	26.5	2hr	3.91	2.30	"	-
8-23-50	6	25.6	4hr35min	4.73	1.96	"	34
8-24-50	7	25.0	3hr55min	4.68	1.64	"	37
"	8	"	7hr10min	"	1.60	"	31
"	9	"	4hr45min	"	1.66	"	35
8-25-50	10	24.8	6hr40min	4.36	1.80	"	29
"	11	"	3hr45min	"	1.98	"	34
				mean 2.02 ± .35			

*Experiments performed at the Waikiki Marine Laboratory.

Table 8a.--Summer lethal values of oxygen for iao

Experiment No.	Temperature	Duration of experiment	O_2 (cc./l.)		Volume of jar	Weight of fish	Length of fish
			Initial	Final			
	°C.				cc.	gm.	mm.
*1	25.9	1hr12min	3.69	1.05	1070	-	-
*2	26.2	1hr22min	5.32	1.27	"	-	-
*3	25.7	1hr30min	6.20	1.38	"	-	-
*4	24.4	1hr05min	5.17	1.01	"	-	-
*5	24.5	1hr23min	5.48	1.28	"	-	-
6	27.3	3hr55min	4.60	1.58	535	-	37
7	27.0	6hr15min	4.50	1.28	"	-	30
8	24.3	8hr55min	4.67	0.94	"	-	25
9	24.0	7hr50min	4.67	1.11	"	-	28
10	26.0	6hr30min	4.72	1.20	"	-	31
11	27.1	2hr	4.38	0.87	"	-	58
12	27.1	2hr45min	4.38	0.86	"	-	50
13	25.3	2hr50min	4.44	1.08	"	1.06	45
14	25.3	1hr30min	4.44	0.75	"	2.80	60
15	25.3	3hr30min	4.44	1.17	"	0.75	41
16	26.5	3hr	4.43	1.41	250	0.57	39
17	25.0	3hr55min	4.36	1.02	"	0.43	36
18	25.2	6hr45min	4.33	1.18	535	0.60	37
19	25.2	4hr	4.33	1.20	"	0.96	44
20	25.1	5hr30min	4.50	0.63	"	1.10	45
21	25.1	4hr15min	4.50	1.18	"	1.10	46
22	25.1	6hr25min	4.50	0.88	"	0.80	42
23	25.1	3hr25min	4.50	1.07	"	1.34	49
mean	25.6 ± 0.9		1.10 ± 0.22				

*Experiments performed at the Waikiki Marine Laboratory.

Table 8b.--Winter lethal values of oxygen for iao

Experiment No.	Temperature	Duration of experiment	O_2 (cc./l.)		Volume of jar	Weight of fish	Length of fish
			Initial	Final			
	°C.				cc.	gm.	mm.
1	23.1	2hr45min	4.60	0.96	535	2.09	54
2	23.1	6hr	4.60	0.82	"	1.08	45
3	23.1	5hr15min	4.60	0.80	"	1.36	48
4	21.3	3hr30min	4.94	1.03	"	1.66	51
5	21.3	4hr30min	4.94	0.86	"	1.52	50
6	21.9	5hr	4.70	1.16	"	1.14	46
7	21.9	5hr05min	4.70	1.14	"	1.49	50
8	21.9	4hr10min	4.70	1.04	"	1.45	50
9	21.6	3hr10min	4.58	1.17	"	1.50	49
10	21.6	3hr10min	4.58	1.16	"	1.49	49
11	21.6	3hr45min	4.58	1.09	"	1.37	48
12	21.6	4hr30min	4.58	0.90	"	1.25	47
13	21.6	4hr05min	4.58	1.21	"	1.00	45
14	21.6	4hr20min	4.58	0.79	"	1.36	49
15	21.4	4hr15min	4.15	0.82	"	1.95	52
16	21.4	45min	1.10	1.02	"	1.06	43
17	21.4	3hr25min	2.01	0.78	"	1.35	47
18	22.3	4hr15min	2.96	0.50	"	1.98	53
mean	$21.9 \pm .6$		$0.96 \pm .18$				

Table 8c.--Analysis of variance of the data from the above two tables

Source of variation	Degrees of freedom	Sum of squares	Mean squares
Total	40	1.8995	-
Seasons	1	0.2152	0.2152*
Within seasons	39	1.6843	0.0431

*Significant at 5-percent level ($P < 0.05$).

Lethal Values of Oxygen for Iao: Experiments Using Several Fish

Procedure.--In these experiments, 10-15 fish (usually 14) were placed in a 1-liter aspirator jar with a side-opening close to the bottom for withdrawing water samples. Water was circulated through the container for 1 hour, at which time the fish were quiescent and appeared to be schooling normally. Circulation was then stopped, about 100 ml. was run out and replaced by mineral oil, after which the jar was securely stoppered. Three samples were taken in each experiment, after approximately one-third, one-half, and all of the fish had died. At the end of the experiment all fish were measured to the nearest millimeter. The tests were run in December 1951 and January 1952.

Results.--Table 9 gives the conditions and results of each experiment, and figure 10 ows graphically the relation between oxygen concentration and percentage of fish dead, the curve ng fitted by the method of least squares, using a log-log transformation of the data. For those periments employing 14 fish, the times to approximately 50-percent mortality are fairly simi-, indicating more or less uniform behavior for the different lots of fish. Comparing the data h the winter lethal values of oxygen obtained from individual fish (table 8b), it is evident that the overall range in lethal values is nearly the same, being 0.55-1.30 and 0.50-1.21 cc./l. respectively. On the other hand, the mean value from table 8b (0.96 cc./l.) is higher than the mean of the values from the present experiments. Inspection of figure 10 indicates that, in the group experiments, practically all the fish died at oxygen concentrations between 0.55 and 0.85 cc./l. whereas figure 11, plotted from the data of table 8b, indicates, for the tests on individuals, a more even distribution over the range of lethal values of oxygen.

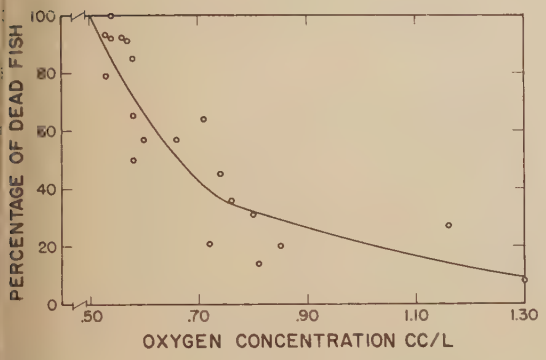

Figure 10.--Lethal values of oxygen for iao: experiments using several fish. Abcissa represents the oxygen content of the water; ordinate represents the percentage of fish dead at the various oxygen concentrations.

Effect of Temperature on Lethal Values of Oxygen for Iao

Procedure.--These tests, in which single fish were used, were performed in a constant temperature apparatus consisting of six compartments separated by tin plates with a thermostatically controlled heating coil in one of the end compartments and a similarly controlled refrigeration unit in the other. The water in the baths was agitated at intervals by compressed air. After allowing 4-5 hours to establish a constant gradient of temperature, the temperature in each of the baths rarely fluctuated more than 0.3°-.4°C., with the hotter baths in general showing the most variability.

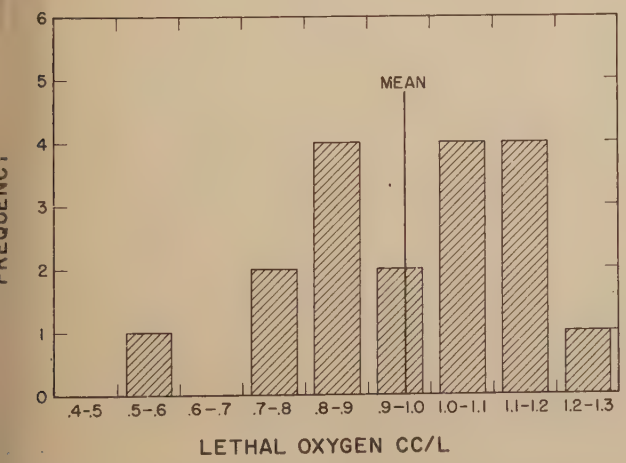

Figure 11.--Frequency distribution of winter lethal values of oxygen for iao, calculated from data of table 8b.

In the experiments, two Florence flasks, each containing one fish, were immersed in each temperature bath. Handling of fish and water sampling were done in the manner described in the previous sections. Excepting a few experiments at 18°C., all tests were made at temperatures ranging from 21° to 31.5°C. Preliminary tests indicated that iao die almost immediately at temperatures over 34°C. but, with the exception of a great increase in activity, appear to behave normally at 31°C. For the tests at 18°C. the fish were first gradually introduced to this temperature by placing a gallon jar containing five fish in the water bath used for the temperature versus oxygen consumption experiments (fig. 2b) and circulating cold water through the copper coils while a slow stream of sea water flowed through the jar. Final equilibrium at 18°-19°C. was reached after 3 to 4 hours, thus avoiding the shock of a sudden

transfer to colder water. After 24 hours at 18°-19°C. no fish had died and all appeared to be in good condition.

Table 9.--Lethal values of oxygen for iao: experiments using several fish

Date	Experiment No.	Number of fish	Average length	Percent dead	O_2	Time for approx. 50% of fish to die	Temperature
			mm.		cc./l.		°C.
12-8-51	1	11	45	27	1.16	-	23.8
				64	0.71		
				91	0.57		
12-11-51	2	14	43	21	0.72	1hr50min	23.0
				57	0.66		
				100	0.54		
12-16-51	3	13	48	8	1.30	-	23.0
				31	0.80		
				85	0.58		
12-18-51	4	14	45	36	0.76	1hr40min	23.0
				79	0.53		
				100	0.54		
12-28-51	5	14	43	14	0.81	2hr15min	23.4
				50	0.58		
				92	0.54		
12-29-51	6	14	46	92*	0.56	2hr10min	22.4
1-3-52	7	10	49	45	0.74	-	23.4
				65	0.58		
				100	0.54		
1-15-52	8	15	45	20	0.85	-	22.0
				57	0.60		
				93	0.53		

*All fish died within 5-10 minutes of each other.

Results.--The experiments were performed in January and February of 1951 and of 1952 and the fish used were therefore taken from waters ranging in temperature from 22° to 23°C. The results are presented in figure 12 and table 10, the points on the graph representing the average value for the two flasks in each bath. Lethal values of oxygen are seen to increase slowly at first (between 20.5° and 23°C.) and then more rapidly above 26°C. In spite of considerable variability in the results at each of the temperature levels, the overall trend is unmistakable. The apparent rise in the lethal value of oxygen at 18°C. is, unfortunately, based on the results of only two experiments and obviously a rigid interpretation cannot be given. Two things may be noted, however; first, the temperature was at least 3°C. lower than any temperature experienced by the iao in its natural environment; and secondly, the period of adjustment to this temperature was probably too short. Both factors could contribute to the high lethal oxygen value obtained.

Table 10.--Lethal values of oxygen for individual iao at different temperatures

Experiment No.	Temperature	Lethal O_2	Length of fish	Weight of fish	Duration of experiment
	°C.	cc./l.	mm.	gm.	
1	30.6	1.13	48	1.25	5hr50min
		1.18	48	1.34	5hr15min
	25.2	0.72	46	1.02	9hr10min
	22.0	0.70	40	0.62	11hr05min
2	31.0	0.94	49	1.52	3hr30min
		1.16	51	1.70	3hr
	26.1	0.74	47	1.27	3hr25min
	22.8	0.74	48	1.26	3hr20min
3	31.3	1.02	46	1.20	3hr15min
		1.12	49	1.46	2hr45min
	25.9	0.82	49	1.59	6hr40min
		0.84	50	1.62	4hr25min
	21.8	1.03	45	1.31	5hr30min
		0.58	50	1.70	6hr
4	30.5	1.21	46	1.20	1hr50min
		1.20	51	1.66	2hr13min
	25.8	0.91	54	1.99	2hr35min
	21.1	0.69	52	1.59	6hr40min
5	30.6	1.16	48	1.25	2hr45min
	27.6	0.97	54	2.17	2hr10min
		1.21	45	1.12	3hr
	25.2	0.91	50	1.41	3hr
		0.80	51	1.46	2hr40min
	20.8	0.78	51	1.54	5hr10min
6	27.8	0.96	56	1.79	2hr45min
		1.04	50	1.54	3hr05min
		0.99	50	1.50	4hr
	21.8	0.72	56	2.47	3hr05min
7	21.2	0.78	55	2.03	3hr25min
		0.74	52	1.85	3hr20min
	*18.0	1.56	41	0.75	5hr30min
		1.70	49	1.00	4hr10min

*Acclimated for 24 hours at 18°-19°C.

Discussion

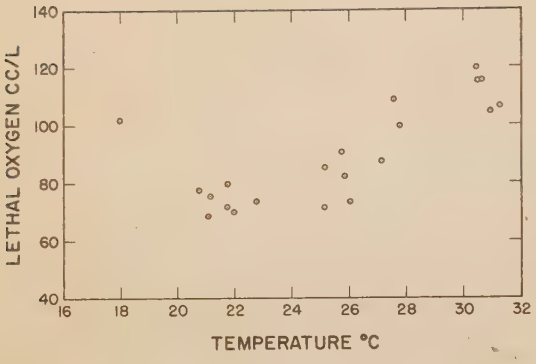

Figure 12.--Lethal values of oxygen at different temperatures. Points represent the average of two trials at each temperature.

Lethal values of oxygen for individual iao ranged from 0.50 to 1.58 cc./l. (combined summer and winter data). There was less variability in the winter data, as evidenced by the smaller standard deviation (0.18 cc./l. as compared with 0.22 cc./l. for the summer data). Some of the variability in any one season's experiments was probably caused by differences in the temperature of the experiments and possibly in the size of the fish used, although the influence of the latter is doubtful. The range of temperatures in the summer experiments was greater than in the winter tests, which could serve to increase the variability of the summer data. Furthermore, in certain instances where fish of exactly the same weight were used, the lethal values of oxygen were identical, but the duration of the respective experiments differed markedly, indicating a marked difference in metabolic rate between the fishes concerned.

Comparing the results on nehu with those of Suehiro (1951), who also worked with individual fish, it was apparent that the variation in his data was greater than that found in the present paper. Standard deviations calculated by the author from Suehiro's data were 0.54 for sardines and 0.44 for anchovies, as compared with 0.35 for the nehu. It is noteworthy that the mean lethal value of oxygen for nehu (2.02 cc./l.) agrees quite well with the mean values found by Suehiro for Japanese bait fishes (2.04 cc./l. for sardines and 1.80 cc./l. for anchovies).

Experiments using many fish gave a lower average lethal value of oxygen than tests on individuals although the range was about the same. The lethal values fell, for the most part, within the range from 0.55-0.85 cc./l. The reason for the lower average value is obscure, but the fish certainly appeared more quiescent when tested in groups rather than individually. Most species of trout appear, like the iao, to have a relatively narrow asphyxial range of oxygen concentrations (Gardner and King 1922, King 1943). Wilding's (1939) curves for three species of freshwater fish (yellow perch, steel-colored shiner, and blunt-nosed minnow) are similar in shape to the one for iao (fig. 10), but the total range in lethal values of oxygen is much greater in his case. It is noteworthy that Wilding withdrew oxygen samples when one or more of the fish showed symptoms of asphyxiation, as evidenced by loss of balance, irregular motion, etc. Complete asphyxiation is perhaps a better criterion to use in controlled laboratory experiments. Wells (1913), for example, states that the "turning-over time" for fish varies considerably within a species, some fish maintaining their equilibrium up to the point of complete asphyxiation. Observations by the writer also indicate a highly variable physical response by iao to lack of oxygen. Comparison with the results of other workers must, of course, be made with caution since the techniques employed are far from standardized. Furthermore, much of the material reported in the literature pertains to field observations on behavior of fish at low oxygen concentrations rather than laboratory experiments.

With the data available, no pronounced relationship between the size of the fish and its resistance to lack of oxygen could be demonstrated. This is somewhat contrary to the results of Keys (1931), who found that larger Fundulus were more resistant to asphyxiation and states that this was due to the smaller oxygen demand per unit weight of the larger fish. Moore (1942), working in the field with several freshwater species, also observed that larger fishes survived critical oxygen concentrations longer than smaller individuals of the same species. On the other hand, Wells (1913) found just the opposite for trout, small fish showing a greater resistance per unit weight than large ones. Suehiro's (1951) data on individual fish present a better comparison with the results reported in this paper. His weights, for both sardines and anchovies, when plotted against the lethal value of oxygen, are even more randomly scattered. It would seem, for iao at

any rate, that regardless of a probable higher metabolic rate in the smaller fish, they are not markedly hindered in their ability to extract oxygen from water low in oxygen content.

A small, but nonetheless statistically significant, difference was found between the mean summer lethal value of oxygen (1.0 cc./l., average temperature 25.6°C.) and the mean winter value (0.96 cc./l., average temperature 21.9°C.). This difference is of about the expected magnitude according to the relationship of temperature to the lethal value of oxygen (fig. 12). In the absence of the appropriate data, however, it is difficult to determine the possible influence of purely seasonal differences in the behavior of the fish.

A few investigators (Gardner and King 1922; Moore 1942; Fry et al. 1947; Graham 1949) have studied the effects of temperature on lethal values of oxygen in fish and found, as in iao, that the lethal level of oxygen increases as the temperature increases. The curve of temperature versus lethal values of oxygen (fig. 12) shows a somewhat steeper rise from 26° to 31°C., roughly corresponding to the pattern shown in the relationship of metabolic rate to temperature (fig. 4). Thus, with a greatly increased metabolic rate at the higher temperatures, the fish is less able to cope with low values of dissolved oxygen. This observation may be of some importance to the live-bait fishery. As mentioned earlier, the fishery is conducted primarily in the summer months, when temperatures often rise above 26°C., particularly in calm anchorages. At the higher temperatures, even a small increase in temperature may bring about a marked decrease in the resistance of the fish to oxygen deficiency.

The lethal values of oxygen reported here from laboratory experiments should be checked by more extensive measurements taken directly from the live-wells of the fishing boats. Such tests might possibly give lethal values intermediate between the average for iao (about 1.0 cc./l.) and that for nehu (about 2.0 cc./l.), since many bait loads are "mixed", containing both nehu and iao.

SUMMARY AND CONCLUSIONS

1. Confinement of tuna baitfish in small live-wells pointed to the desirability of a study of the oxygen requirements of the fish. Experiments were designed to determine lethal levels of oxygen and the rate of oxygen consumption under various conditions. In the oxygen consumption experiments special emphasis was laid on the effects of crowding, flow-rates, and the oxygen concentration of the water.

2. A flowing-water method was used to measure oxygen consumption, dissolved oxygen being determined by the unmodified Winkler procedure. For tests of lethal values of oxygen, where the fish were asphyxiated in sealed jars, the permanganate modification of Winkler's technique was employed.

3. The results are summarized below:

   a. From serial observations, it was evident that oxygen consumption in the iao showed considerable hour-to-hour fluctuation even when there were no outward signs of increased or decreased activity on the part of the fish. No rhythmic cycle in metabolic rate could be demonstrated, at least during the first 24 hours in the container.

   b. Oxygen consumption increased with increase in flow-rate, the effect being perhaps more pronounced in the summer months. In addition, oxygen consumption per unit weight was significantly lower in the tests with large numbers of fish. Possible reasons for the latter finding were discussed.

   c. The "critical oxygen level", i.e., the point at which the rate of oxygen consumption became dependent upon the oxygen concentration of the water, could not be precisely delimited but lay somewhere between 1.5 and 2.5 cc./l. Below this level, both breathing rate and oxygen consumption steadily decreased.

d. Individual iao showed marked differences in resistance to oxygen deficiency. Lethal values of oxygen ranged from 0.50 to 1.58 cc./l., the mean of the summer tests being 1.10 cc./l. and of the winter tests, 0.96 cc./l. A similar range in lethal values was obtained from the experiments where several fish were asphyxiated at once, but almost all the values fell within the narrow interval from 0.55 to 0.85 cc./l., depressing the average to 0.69 cc./l.

e. Over the temperature interval from 19° to 29°C., the rate of oxygen consumption increased slowly at first and then more rapidly at the higher temperatures. Lethal values of oxygen, measured over the same range, also showed a greater increase between 26° and 31°C.

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OBSERVATIONS OF SKIPJACK SCHOOLS IN HAWAIIAN WATERS, 1953

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FISH AND WILDLIFE SERVICE

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The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

OBSERVATION OF SKIPJACK SCHOOLS IN HAWAIIAN WATERS, 1953

By

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ABSTRACT

On six cruises around the Hawaiian Islands during 1953, 90 days were spent intensively searching for skipjack (aku) schools. Six flights in U. S. Navy PBY amphibians were also made. The purposes were to evaluate and improve the scouting techniques and to determine the distribution of the skipjack.

Skipjack schools are located almost entirely by accompanying birds which flock and maneuver characteristically when working over them. Flocks are seen out to 4 miles from the vessel, but most are seen within 2 miles. A new method of estimating the scanning efficiency indicates that only 6 percent of total flocks are seen beyond 2 miles, and 38 percent between 1 and 2 miles. Many flocks were missed. Careful scanning aft of the vessel on autumn cruises resulted in a 22 percent increase in number sighted.

Numerous factors affecting the occurrence of flocks and the methods of sighting them were investigated. Poor weather conditions reduced the proportion of flocks seen. Large flocks were seen farther from the vessel than small ones. Fishermen maintain consistent watches and are good at estimating distances. In April more flocks were seen in early morning and mid-afternoon; in June more just before noon and in the autumn they were randomly distributed during the day.

Airplane scouting is much less effective than vessel scouting, probably because the dark-colored birds cannot be seen against the water.

The Hawaiian fleet catches three-fourths of its skipjack within 20 miles of land, but schools are not more abundant there. There was no decline in abundance with distance from land out to 230 miles northeast and 350 miles southwest of Oahu.

More schools were seen southwest of Oahu in February, September, October, and November; more to the northeast in April and June.

One location, near an eddy, contained much larger numbers of schools during the September and October cruises. This eddy may enrich the waters, and it will be studied much more intensively.

A peak in the seasonal cycle of number of schools seen occurred in April, not when the catch was greatest in June to August. It is shown that the schools observed in April contained smaller fish and the fishermen fished fewer of them.

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For at least the past two decades the Hawaiian skipjack or "aku", Katsuwonus pelamis (Linnaeus), has provided a major part of Hawaii's fish production. Except for the war years, when there was almost no fishing, the skipjack fleet has consisted of about 20 to 25 boats, which have landed about 10,000,000 pounds annually. This comprises from one-half to two-thirds of the total fish production of the Territory (June 1950). Virtually all of the skipjack are taken by trolling the schools of fish with live bait and catching the fish with pole and line from the stern of the vessel.

The nearly constant fleet and the absence of any clear up or down trend in 20 years suggest that it has not been economical to enlarge the fishery. There appear to be two major limiting factors, the first of which is a shortage of the essential live bait. The second is a pronounced seasonal fluctuation, with high catches from about June to September and poor catches during the balance of the year. Clearly, expansion of this fishery involves alleviation of these two limiting factors, and the Pacific Oceanic Fishery Investigations (POFI) has commenced work on both problems. This report presents the results of the first year's study on locating the fish, particularly in areas where and at times when they are not available to the local fishery. In addition a comparison and evaluation of vessel and airplane scouting techniques have been made.

The study got under way in September 1952, using the research vessel CHARLES H. GILBERT, which had been completed in May 1952. After two shakedown cruises, observations on skipjack were begun. Cruises 3, 6, 8, and 12 were made near shore for testing artificial bait or for bait surveys. Some scouting was done on these cruises, but it was incidental to other objectives. On cruise 7, in February 1953, scouting was the principal objective, and a standard scouting technique was developed which was used on cruises 11 and 13, in April and June 1953 respectively. Subsequently the HUGH M. SMITH was used for the standard scouting on cruises 22 to 24 from September to December 1953. The second vital part of the scouting program was made possible by the U. S. Navy, which furnished a PBY amphibian plane for six flights between November 1952 and June 1953.

The authors are greatly indebted to many members of the POFI staff who assisted with the field observations, particularly to John W. Slipp, who was in charge of the skipjack investigation until July 1953 and who standardized the methods of observing the bird flocks and fish schools. Also deserving special mention are Daniel T. Yamashita and Heeny S. H. Yuen, who with Slipp and Otsu served as field party chiefs, and Albert K. Akana, Jr., Robert E. K. D. Lee, and Gordon M. Wilkinson, who captained the vessels on the cruises. We received excellent cooperation from all U. S. Navy personnel concerned with the flights and from Rear Admiral W. K. Phillips, who directed that the aircraft be made available.

Valuable assistance was also received from Mr. Vernon E. Brock, Director of the Division of Fish and Game of the Board of Agriculture and Forestry of the Territory of Hawaii, who made available statistics on the skipjack fishery and who encouraged us in this study.

METHODS

Vessel Scouting

Our principal method of scouting follows the practice of the local skipjack fleet. We employ experienced local fishermen, who maintain a constant watch from the bridge of the vessel while cruising at the normal speed of 9 to 10 knots. These men locate the schools by the presence of bird flocks, and from the species of birds present and their behavior they can make remarkably accurate guesses about the kind and size of fish that are below them. Fortunately for the skipjack fishermen, approximately 90 percent[1/] of the schools of fish which are to be found by the presence of birds in Hawaiian waters are composed of skipjack, the balance being mostly dolphin (mahimahi), small yellowfin or bigeye tuna (ahi), or little tunny (kawakawa). [2/]

Apparently the practice of using bird flocks for locating tuna schools is widespread throughout the Pacific region. According to Cleaver and Shimada (1950), the Japanese live bait fishermen rely heavily on birds for locating skipjack schools when they are in the area where schools are to be expected. The Japanese fishermen also expect to find skipjack schools near floating driftwood and debris, or in the vicinity of whales and basking sharks. In addition they sometimes find fish by seeing the wake of the school or fish actually jumping and rolling on the surface.

In Hawaiian waters the fishermen are almost completely dependent upon the birds for locating tuna. In fact, while they occasionally sight schools not accompanied by birds, on the two principal scouting cruises of the CHARLES H. GILBERT during the spring of 1953, every one of the 253 fish schools sighted was accompanied by birds and was found by means of the birds. Undoubtedly this dependence on birds arises partly from their prevalence and partly also from the almost constantly choppy sea conditions with white caps which make it extremely difficult to see the wake of a school or jumping fish at any considerable distance from the vessel.

Because they rely on the birds, the fishermen adapt their scouting technique to sighting flocks of birds from the deck of the vessel rather than from a crow's nest. Since the Hawaiian sea birds which flock over tuna schools are predominantly dark in color, e.g. wedge-tailed shearwater, sooty and noddy terns[3/], and the ocean is characteristically a very deep blue, they are best seen above the skyline. Fishermen on the bridge of the vessel, when they think they detect a flock of birds at a maximum distance, will frequently take the binoculars down to the deck, where they can see more easily. Apparently this method of scouting is quite different from that which prevails in the American tuna fishery off Central America. According to fishermen who have fished there, they depend primarily upon seeing the wake or shadow of the school or jumping fish. They also find fish by fishing near drift logs, under birds, or near porpoise schools. However, the actual fish school is best sighted at a maximum distance by observing from as high as possible, and the practice is continually to scan the surface from the masthead. No doubt this technique is more effective because of the prevalence of calm water conditions in that area, and also, we suspect, because of larger and denser schools of tuna.

Our system of scouting is designed to secure as continuous a scanning of the horizon by experienced local fishermen as is practicable. The men are assigned 2-hour watches, and each follows the usual fishing practice of making a thorough search of the horizon with the naked eye

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[1/] A value which we cannot precisely substantiate. According to fishermen's estimates on the basis of bird behavior, 75 out of 83, or 90 percent, of the schools sighted during GILBERT cruises 11 and 13 were skipjack. We positively identified 55 schools that we tried to chum, and 47, or 85 percent, were either skipjack or a mixture of skipjack with other species.

[2/] Coryphaena hippurus Linnaeus, Neothunnus macropterus (Temminck and Schlegel), Parathunnus sibi (Temminck and Schlegel), and Euthynnus affinis Cantor in the order named.

[3/] Puffinus pacificus, Sterna fuscata, and Anous stolidus in the order named.

and with binoculars about once each 5 minutes. During the first half of 1953 the men concentrated their search on the forward quadrants of the horizon in accordance with their usual practice. Following some study of the data and development of a theory that schools intermittently sound and are not detectable for periods of time, the fishermen were instructed to search the after quadrants of the horizon as carefully as they did the forward quadrants. After finding fair numbers of schools, some of them directly astern of the vessel, the fishermen were convinced of the necessity of this, and we believe that subsequently we achieved uniform attention to all sectors of the horizon.

Whenever a school of fish accompanied by birds was sighted, the scientist on watch was immediately notified and he maintained a minute-by-minute record of the behavior of the birds, the bearing of the school relative to the course of the vessel, which was never altered until the school was abeam, and the estimated distance of the school from the vessel. After the school was abeam, we frequently approached and fished it, if bait was available.

Estimates of distance over the open sea are expected to be subject to a great deal of error. We are convinced, however, that our fishermen obtain consistent and reasonably accurate estimates of the distances of schools from the vessel. The consistency is evident in data which will be subsequently discussed. The distances were estimated to the nearest 1/4 mile when under about 2 miles and usually to the nearest 1/2 mile from 2 to 4 miles. The smoothness of the frequency curves of schools sighted against distance indicates that there is no important tendency to favor a particular distance over adjoining distances. Various methods of checking the accuracy were tried, including the use of a range finder, a stadimeter, and a sextant. None of the conventional methods for measuring distance under such conditions proved practical, but we did find that with a calm sea large flocks of birds could be detected and their distance accurately measured by radar. On two occasions we obtained radar measurements independent of the fishermen's estimates, and we found good agreement (table 1). Apparently the fishermen have developed a very considerable skill in estimating the distance to birds by relating their appearance to the average time required to run them down.

Table 1.--Comparison of estimated distance and radar distance of bird flocks

a. CHARLES H. GILBERT cruise 12 - May 11, 1953 (about 80 birds in flock)

Time	Fishermen's estimate	Corresponding radar reading 1/
1142	1 mile	0.8 - 0.9 mile
1143	1 mile	0.5 - 0.7 mile
1144	1/4 mile	0.3 - 0.6 mile
1145	1/3 mile	0.2 - 0.5 mile
1146	1/5 mile	0.1 - 0.4 mile
1147	100 yards	----

b. HUGH M. SMITH cruise 22 - September 8, 1953 (about 300 birds in flock)

Time	Fishermen's estimate	Corresponding radar reading 1/
1556	1-1/2 miles	2 miles
1600	1-1/2 miles	1-3/4 miles
1601	1	1-3/4 miles
1603	1 mile	1-1/2 miles
1604	1-1/2 miles	1-3/4 miles

1/ The radar readings indicate the spread of the rather diffuse first flock (May 11, 1953) and the middle of the more compact second flock (September 8, 1953).

The areas to be scouted with the vessel were selected to include and extend beyond those fished by the local fleet, but they were, of course, severely limited by the distance that a single vessel could travel. A series of courses in the form of crosses was decided upon, as shown in figure 1. These tracks were followed carefully on GILBERT cruises 11 and 13, which contributed the bulk of our observations for an evaluation of scouting techniques in the subsequent sections. The other GILBERT cruise that provided some data was cruise 7, which followed the track indicated in figure 2. The cross patterns have the advantage of providing replicate coverage of the same area on successive days. They also serve to standardize the heading of the vessel in relation to the sun and to the prevailing seas, which the trade winds usually push from the northeast quadrant. Also, early in the investigation it was expected that the schools of skipjack might be migrating through the areas and that such a pattern of scouting might show a "Doppler effect"[4/], which would indicate the direction and speed of the schools. However, no Doppler effect was found, and the cross pattern wasted the time of the vessel during the night because it was not possible to use that period to move the vessel to another scouting location for the following day.

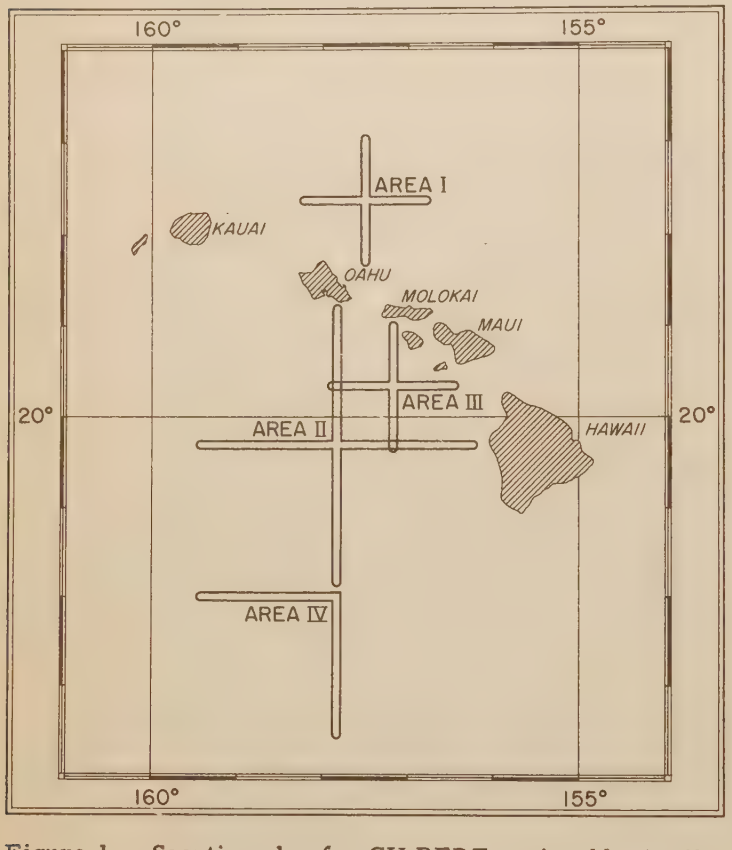

Figure 1.--Scouting plan for GILBERT cruise 11, April 11 to 28, Areas I and II, and for GILBERT cruise 13, June 13, to July 11, all areas.

During the autumn of 1953, a different scouting plan was developed in which a particular area was scouted during a day and then the night was used to move on to another area. This plan consisted of S-shaped courses, as shown in figure 3, which provided an estimate of the number of schools to be sighted within an area in which the schools could be assumed to be randomly distributed. Such an assumption avoided the troublesome problem of deciding whether a concentration of schools sighted during a particular part of a day on a straight run arose from chance variation or for some special reason. It also avoided the troublesome west to east run on which the prevailing northeasterly tradewinds frequently caused the vessel to take spray over the bridge, resulting in poor scouting conditions. The length of this S-shaped section was 95 miles or about 10 hours' running time. With about 12 hours of daylight this left 2 hours for fishing schools and experimenting with them. Night was then almost fully utilized in the run to the next station. This plan resulted in covering areas out to 230 miles northeast and 350 miles south and west of Oahu.

[4/] The name is given to the physical effect of an apparent change in the frequency of sound or light where observer and source are approaching or separating. A similar difference might be expected if a given number of fish schools were meeting or traveling with the vessel.

Airplane Scouting

Airplanes have come into increasingly common use for locating fish in various parts of the world. Harrison (1931) reported that planes were successfully used for locating schools of menhaden off the North Carolina coast. Cushing et al. (1952) discussed the use of planes and helicopters, particularly in the American tuna fishery, where they reported that schools of tuna more than 20 miles away have been spotted from the air and that under usual conditions much more can be seen from the plane above altitudes of 600 feet. However, Sette (1949) felt that the method was not satisfactory for locating pilchard off California, where the scouting was done by day, the fishing by night. Blackburn and Tubb (1950) found that planes aided in exploratory work in Australia, but the observations left much to be desired over waters where many different species were schooling. Then, too, planes have been previously used for locating skipjack in Hawaiian waters, although it was reported to us that the trials were not extensive enough to demonstrate their value. Clearly, plane scouting was a likely method of locating skipjack and we undertook to test it.

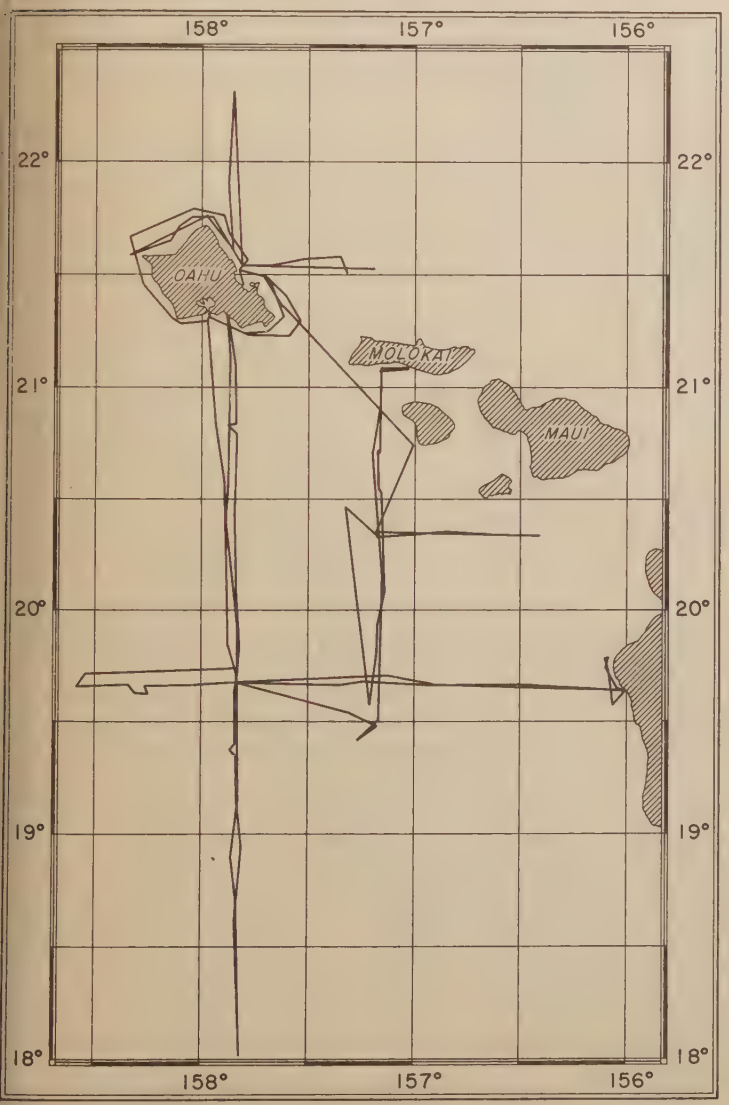

Figure 2.--Track chart, GILBERT cruise 7, in February.

Through the cooperation of the United States Navy at Barbers Point, Oahu, six flights were made between November 14, 1952 and June 15, 1953. These flights were made in an amphibious PBY plane, which was ideal for our aerial scouting because it had a relatively low cruising speed of approximately 100 knots and it had large blisters, where four observers could conveniently be located, on the fuselage just forward of the tail assembly.

Since this was our first attempt at aerial scouting, the scouting procedure was necessarily modified several times before a more standardized technique could be developed. Following is a summary of the procedures employed:

The first method was to have each observer work independently throughout the entire flight and record his own observations. This method sometimes produced confusing records in which it was impossible to determine whether two observers had recorded the same object or whether they had recorded separate objects at the same time.

An improved method was to divide the observers into two teams, placing a team of two on each side of the plane. A member of each team scanned from a point directly below the plane to an angle of about 30° from vertical on one side, the other outward from this point.

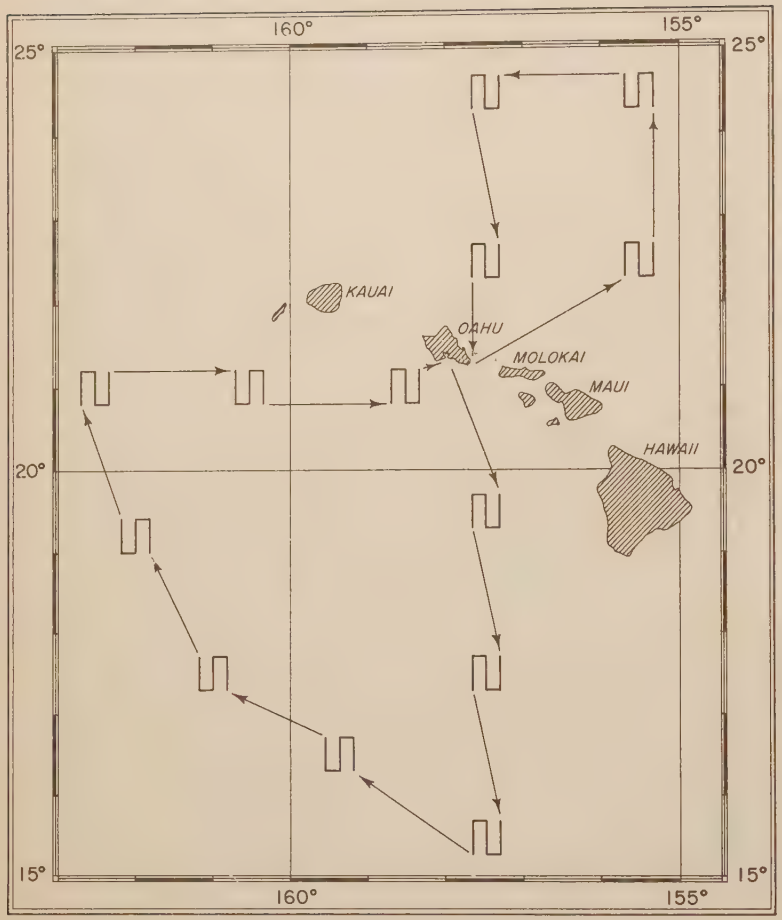

Figure 3.--Scouting plan for cruises 22, 23, and 24 of the HUGH M. SMITH in September, October, and November.

These inner and outer zones were exchanged between observers each 20 minutes. The observer scanning the outer zone was also charged with the responsibility of keeping the team's records as well as making periodic observations of weather and sea conditions. Unfortunately, communication between observer and recorder was a serious problem in the noisy interior of the plane. This problem was alleviated when each observer was required to keep his own record. During the last flight each observer was also required to measure and record the angle from vertical of each object sighted.

The flights were about 4-1/2 hours long and covered a distance of approximately 450 miles. The flight track was usually laid out over an area which was being scouted by the CHARLES H. GILBERT and, in addition, covered areas where skipjack were likely to occur (fig. 4). The plane flew at altitudes between 500 and 2,000 feet on the various flights, but a constant altitude was maintained during each flight except occasionally, when the plane descended to lower elevations to examine objects more closely or repeatedly. On several flights a Navy photographer accompanied the plane to photograph objects of special interest. Records were maintained of the time and sighting of all fish, birds, and aquatic mammals and also the condition of the sea surface. Since frequent navigational fixes were obtained by the Navy crew, it was possible to construct a detailed chart combining track and sightings.

Despite the minor differences in techniques, we believe that we maintained a very high scanning efficiency on all flights. Usually the personnel included someone experienced in searching for skipjack schools from a vessel. There was much interest in making the flights and they were short enough to avoid undue fatigue and eye strain.

Behavior of Birds in Relation to Fish

Terns and shearwaters are most commonly seen in association with skipjack schools in the Hawaiian waters and the fishermen consider both to be indicators of skipjack's presence (table 2). Among the terns, the noddies and the sooty tern are the species most commonly seen. The noddies are generally more abundant near the islands while the sooty terns range as far as we have searched. The shearwaters and petrels are a difficult group of birds to identify in flight but the wedge-tailed shearwaters have been found to be very common. These also are found to the limit of our scouting area.

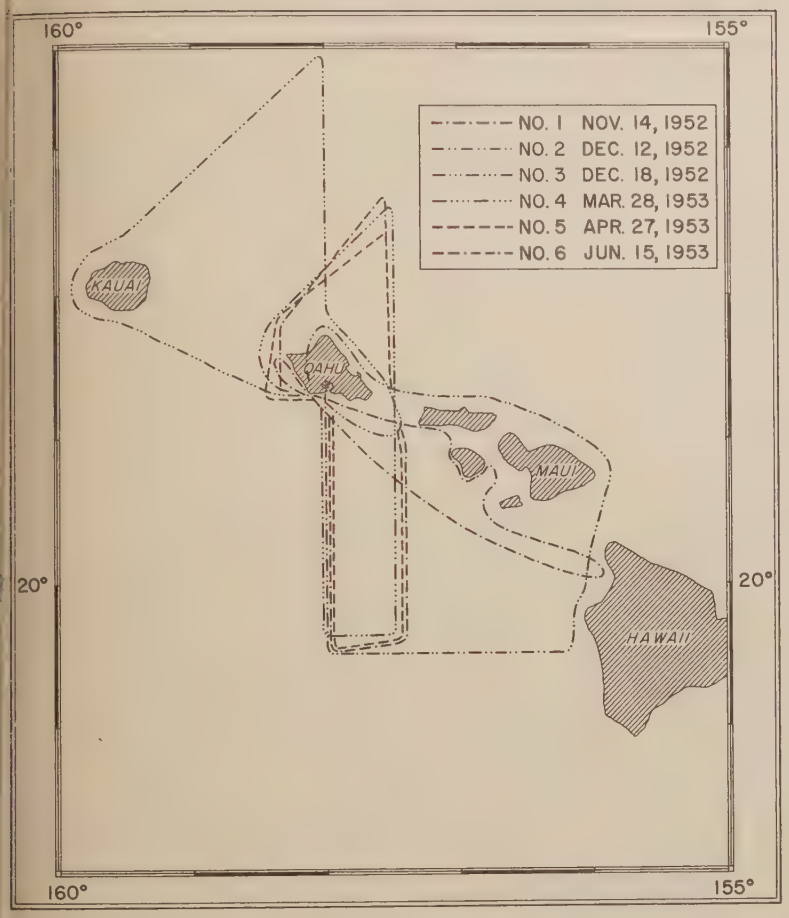

Figure 4.--Tracks of airplane scouting flights.

The most obvious difference in the composition of the bird flocks in our scouting area was the presence of boobies (Sula dactylatra) close to land. In our scouting in April and June 1953 (table 2) none were found in area IV or the southern part of area II, both of which are beyond 100 miles from land. White terns may be more abundant farther from land, but the numbers seen were too small to be important. The other principal groups--terns, shearwaters, and frigate birds--appear in the flocks without regard to the distance from land in our scouting area.

The terns are believed by the fishermen to be the most important species as they are considered to be the "leaders" of the flock; their movements closely paralleling those of the fish. The captain of a fishing boat generally observes the behavior of the terns in order to intercept the head of the school successfully.

Bird behavior is thought to give a generally reliable indication of whether a school is composed of tunas or of dolphin (mahimahi), the number in the school, and the size of the fish. Birds which alternately fly very high, then low, diving almost vertically to the surface and then rising just as steeply to great heights, continuing this behavior, suggest--to the fishermen--the presence of a dolphin (mahimahi) school. This behavior appears to be independent of the species of birds involved, as terns, shearwaters, and boobies all show it. Other behavior suggests tuna schools, the great majority of which, in Hawaiian waters, are skipjack with only occasional yellowfin, bigeye, or little tuna schools. The size of the fish in a school may also be indicated by birds, for they are thought to dive and circle faster and more erratically over small fish, perhaps because the small tuna have a shorter turning radius.

The size of the fish schools is judged by the spread of the bird flock rather than by the number of birds involved. A small school is expected with a compact group of birds. A flock scattered over a large area or broken up to form several smaller groups near each other suggests a large school. In Japanese waters..."as a rule the size of the fish school is thought to be proportional to the number of accompanying birds; the greater the number of fish, the larger the flock" (Cleaver and Shimada 1950).

A high-flying flock is believed to indicate a fast-moving school which is not actively feeding at the surface. An actively feeding school is characterized by "working" birds which are seen continuously diving in amongst the fish. (Fishermen often forgo schools with inactive high-flying birds without making any attempt to fish them, and select schools with "working"

birds.) A school may intermittently sound to greater depths after feeding actively for a while. This is generally shown by the birds, which stop "working" whenever the school sounds. Occasionally, when a school is completely lost, the birds rest on the surface of the water. Such resting birds are believed to signify fish at greater depths.

Table 2.--Composition of bird flocks on two CHARLES H. GILBERT scouting cruises

Cruise	Area	Number of flocks	Number of flocks with						
			Noddy and sooty terns	Shearwaters	Boobies	Tropic birds	Frigate birds	Albatrosses	White tern
GILBERT 11, April 1953	I	46	46	46	33	1	7	-	-
	II	59	54	59	15[1/]	2	18	1	4
GILBERT 13, June 1953	I	47	47	43	17	1	12	-	-
	II	53	53	53	12[1/]	3	11	-	5
	III	5	5	5	2	-	2	-	-
	IV	31	31	31	-	3	14	-	1

[1/] None in southern part of area.

In addition to the terns and shearwaters, the frigate bird (Fregata minor), which usually does not flock, is also a species important to the Hawaiian fishery. One to five of these birds frequently hover high over a flock of terns and shearwaters, and the fishermen believe that their presence indicates a good-sized skipjack school which can be successfully fished. In any event these large (wing spread 5 to 7 feet), high-flying birds can be seen great distances, and on several occasions we have discovered low-flying flocks after noticing a high-flying frigate bird.

In addition to the flocks of oceanic birds which were obviously feeding or "working", some migrating flocks were seen. At the two westernmost stations on the November cruise (SMITH cruise 24) a total of 10 tightly clustered flocks were sighted flying near the sea surface. They were all headed about southwest at carefully estimated speeds of 40 to 60 knots. None were captured or seen closely enough to establish positive identification, but they were tentatively identified as a species of shearwater other than the common wedge-tailed one. These flocks, of course, were not included in our counts of "working" flocks.

EVALUATION OF VESSEL SCOUTING[5/]

Distance and Bearing of Flocks from Vessel

Our fishermen, who are accustomed to looking for bird flocks, can spot them as much as 4 miles from the vessel, and even without the assistance of binoculars they can see birds 2 to 3 miles away. However, on GILBERT cruises 11 and 13 the vast majority of the flocks were first seen within 2 miles of the vessel and many were not seen until a half mile or less from the vessel (table 3).

The relation among the numbers sighted at the various distances when first seen provides an estimate of the efficiency of sighting. We have in table 3 the actual number seen in each successive, concentric, half-mile-wide, semicircular segment of the scanning area ahead of the vessel. If we transform these to the number per unit area (a square mile is convenient) and imagine that the unit area is approached repeatedly, then we have a series showing the number of

[5/] Most of this analysis was prepared immediately after GILBERT cruise 13 in order to provide a basis for planning SMITH cruises 22, 23, and 24. On these latter cruises only 94 more flocks were seen, which add little to the evaluation of many factors affecting the scouting. Consequently the SMITH cruises are considered only where the data make a significant contribution.

schools seen when the vessel was at various distances from the unit area (fig. 5). A simple accumulation of these may be transformed to a percentage of the total number seen in that area. Thus only 0.2 percent were seen in the most distant zone, including 3-3/4 and 4 miles, 5.9 percent had been seen when the vessel had approached within 2-1/4 miles, and only 42.4 percent of the total number seen had been seen when the vessel approached to less than 1-1/4 miles.

Table 3.--Relation of distance from vessel and number of flocks seen on GILBERT cruises 11 and 13[1/]

Estimated distance miles	Number seen[2/]	Square miles of scanning area[3/]	Number seen per square mile	Cumulated number per square mile	Cumulated percent seen
3-3/4, 4	2	6.082	0.3	0.3	0.2
3-1/4, 3-1/2	3	5.301	0.6	0.9	0.6
2-3/4, 3	5	4.516	1.1	2.0	1.3
2-1/4, 2-1/2	26	3.731	7.0	9.0	5.9
1-3/4, 2	44	2.945	14.9	23.9	15.7
1-1/4, 1-1/2	88	2.160	40.7	64.6	42.4
3/4, 1	51	1.374	37.1	101.7	66.8
1/4, 1/2	31	.614	50.5	152.2	100.0
Total	250				

[1/] Three flocks omitted because of incomplete data.

[2/] Three seen in after-quadrants. The entries in this column are the sums of the schools sighted at quarter-mile intervals listed in the stub.

[3/] In two forward quadrants only.

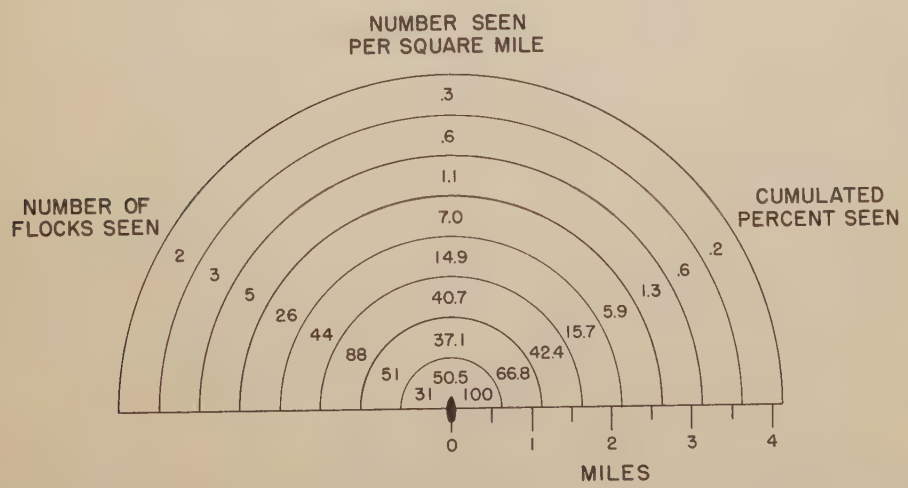

Figure 5.--Flocks seen in concentric segments of the scanning area on GILBERT cruises 11 and 13.

If we consider these percentages to be estimates of efficiency, several assumptions must be made. First, movement of schools in and out of the scanning area before detection must have been equal. Second, it is necessary to assume that the speed and course of the fish schools and accompanying bird flocks were unrelated to the speed and course of the vessel. Since the skipjack

are suspected of considerable annual migrations, which it was thought, when the scouting patterns were planned, might be detectable by a "Doppler effect", this assumption may appear unjustified. However, our data, which will be presented in the section on migration of skipjack schools, indicate that no such effect was detectable and that the movement of schools while being watched approximated a random motion.

Another necessary assumption which appears to be well justified is random distribution of schools in the scanning area. The totals seen in the starboard and port forward quadrants on runs in the various directions during GILBERT cruises 11 and 13 are shown in table 4. The data suggest a tendency toward more sightings in the starboard quadrant, but the difference between starboard and port quadrants is not statistically significant by a chi-square test. The total number of flocks seen according to the relative bearing from the bow did show a significant tendency to increase at bearings between 30° and 60° during the spring scouting (table 5). However, this appears to be associated with characteristics of the vessel and habits of the fishermen. The GILBERT has a rather high bow and a mast and shrouds forward of the bridge, where the observer stands, which tend to obscure vision directly ahead of the vessel. Also, the fishermen perhaps pay somewhat less attention to the area directly ahead of the vessel, because they believe that any flocks in that area will be approached by the vessel and be seen eventually. Quite likely these two factors resulted in a lesser number seen directly ahead of the vessel and a somewhat greater number in the 30° to 60° sector.

Table 4.--Number of flocks sighted in forward quadrants by course run on GILBERT cruises 11 and 13[1/]

Side	Direction								Total
	East to west		West to east		North to south		South to north		
	CHG-11	CHG-13	CHG-11	CHG-13	CHG-11	CHG-13	CHG-11	CHG-13	
Starboard	16	36	11	18	20	10	14	10	135
Port	13	31	8	14	16	9	7	15	113

[1/] A total of 5 flocks (3 seen in after-quadrants, 2 with incomplete data) omitted from this tabulation.

Table 5.--Number of flocks by relative bearing from bow

Relative bearing[1/]	GILBERT cruises 11 and 13	SMITH cruises 22-24
0° - 30°	73	23
30° - 60°	103	25
60° - 90°	72	29
90° - 120°	1	6
120° - 150°	2	2
150° - 180°	0	9
Unrecorded	2	0

[1/] Starboard and port sides combined.

Finally, it is necessary to assume that all of the flocks and schools within 1/2 mile of the vessel were seen. Unquestionably this is true of the bird flocks, but the flocks habitually assemble and disperse while accompanying fish schools, and the assumption that all of the fish schools which approached within a half-mile of the vessel were accompanied by bird flocks at that particular time may not be justified. The ease with which a considerable flock of birds is seen at a distance of 2 miles is not compatible with an estimate that an average of only 5.9 percent of the flocks are seen beyond that distance. Unquestionably the birds are missed to a major extent because they are not assembled into a flock and behaving as they do when they are chasing a fish

school. This suggests that considerable numbers of fish schools are completely escaping attention because they are neither visible on the surface nor accompanied by birds. If this is the case, then our estimates of efficiency are maximal.

Suspecting that schools were being missed, we instructed the fishermen to take special pains to watch all parts of the horizon - astern as well as ahead. Soon after these instructions were issued a large school was located only about a half-mile behind the vessel--directly in its wake--which emphasized the need for looking astern. Consequently, during the fall scouting with the SMITH, 17 of 94 schools were seen off the quarter, and if we assume that these would have been missed by our previous technique, then we saw 22 percent more schools. We note also that the distribution of schools in the forward section is nearly uniform, which is gratifying because vision from the bridge of the SMITH is unobstructed forward and therefore the distribution is approximately as expected.

Size of Flocks

If we consider that the flocks accompanying the skipjack schools vary in size from less than 10 to several hundred birds, it appears probable that the size of the flock will affect the efficiency of sighting it. Our data support this probability. In table 6 we have tabulated the number of flocks seen at each distance according to whether they were large (more than 100 birds), medium (50 to 100 birds), or small (less than 50 birds). The data indicate that large flocks were seen farther from the vessel and much more efficiently at distances from 1 to 2 miles. Medium-sized flocks were seen at medium efficiencies, but perhaps most striking is the comparatively large proportion of small flocks (47.9 percent) which were first seen within a half-mile or less from the vessel.

Table 6.--Comparison of numbers of flocks of various sizes seen on GILBERT cruises 11 and 13[1/]

Estimated distance (miles)	Large (100 or more birds)		Medium (50-100 birds)		Small (50 or less birds)	
	Number of flocks seen	Cumulated percent seen	Number of flocks seen	Cumulated percent seen	Number of flocks seen	Cumulated percent seen
3-3/4, 4	1	0.7	1	0.3	0	0.0
3-1/4, 3-1/2	1	1.4	1	0.6	1	0.3
2-3/4, 3	1	2.1	3	1.8	1	0.7
2-1/4, 2-1/2	10	11.5	10	6.1	6	3.3
1-3/4, 2	13	26.8	22	18.1	9	8.3
1-1/4, 1-1/2	16	52.6	41	48.4	31	31.9
3/4, 1	12	82.9	22	74.0	17	52.1
1/4, 1/2	3	100.0	10	100.0	18	100.0
Total	57		110		83	

[1/] Three flocks omitted from table because of incomplete data.

Weather and Sea

In Hawaiian waters visibility and sea conditions are remarkably uniform. Visibility is almost always excellent, though reduced occasionally by haze, which is troublesome at distances of more than 8 to 10 miles, and by rain squalls, which are almost always temporary. Neither of these troubles had any important effect on scouting conditions, and it is possible to consider that visibility is essentially constant. The sea conditions, however, are usually choppy and affect vision according to the amount of spray thrown over the vessel. This, of course, also depends on the vessel's course in relation to the wind and sea, and since the wind is usually from the northeast quadrant, certain compass courses are habitually affected more than others.

Scouting conditions were classified as follows:

Good- good visibility in all directions, vessel not taking any spray on bridge and sailing smoothly, binoculars usable regularly.

Fair- good visibility in all directions but occasional spray, usually from one side of the vessel, hampering regular use of binoculars on that side; one door on bridge usually closed because of spray, vessel with moderate pitch or roll.

Poor- fairly continuous spray over bow to bridge deck, impossible to use binoculars, heavy pitching and rolling of vessel.

The relation of scouting conditions to direction of travel of vessel is shown in table 7, which shows the scouting performed on GILBERT cruises 11 and 13 along the courses shown in figure 1. In executing these patterns the day's run was always toward one of the cardinal points of the compass. The east to west runs were almost always performed under good conditions whereas the west to east runs encountered almost all of the poor conditions. Both northward and southward runs were performed under about equal amounts of good and fair conditions.

Table 7.--Summary of hours scouted and flocks seen under good, fair, and poor conditions on GILBERT cruises 11 and 13

Direction of travel	Hours	Condition		
		Good	Fair	Poor
West	85	82	1	2
East	84	13	20	51
South	84	45	35	4
North	86	43	43	0
Total hours	339	183	99	57
Total flocks	253	158	65	30
Flocks per 10-hour day		8.6	6.6	5.3

The scouting conditions have surprisingly little effect on the relative efficiency with which schools are sighted at varying distances. Table 8 shows the number seen under each condition of scouting at various distances and the estimated percentages. The estimated percentages seen under good and fair conditions are not significantly different at any distance. However, no schools were seen under poor conditions beyond 2 miles, and the numbers seen at the shorter distances are small enough to introduce a large variability due to chance.

A further comparison of the average number seen per day (table 7) indicates that 38 percent fewer schools were seen under poor conditions than under good conditions, and the fair conditions were but little better than the poor. These differences are large enough to be expected by chance (as indicated by a chi-square test) only about once in 50 times; hence they are statistically significant. Since the variation in conditions arose almost wholly from the heading of the vessel relative to the northeasterly trade winds, differences in the number seen must either have been due to visibility or to a Doppler effect resulting from a migratory movement of the fish in one generally consistent direction. It will be shown in a later section that the latter was probably not responsible.

Table 8.--Comparison of number of flocks seen under various scouting conditions on GILBERT cruises 11 and 13[1/]

Estimated distance (miles)	Good[2/]		Fair		Poor	
	Number seen	Cumulated percent seen	Number seen	Cumulated percent seen	Number seen	Cumulated percent seen
3-3/4, 4	2	0.3	0	0.0	0	0.0
3-1/4, 3-1/2	2	0.8	1	0.5	0	0.0
2-3/4, 3	2	1.2	3	2.4	0	0.0
2-1/4, 2-1/2	15	5.5	11	10.2	0	0.0
1-3/4, 2	29	16.0	11	20.0	4	6.6
1-1/4, 1-1/2	57	44.3	18	42.2	13	34.7
3/4, 1	29	66.9	14	69.5	8	62.0
1/4, 1/2	19	100.0	7	100.0	5	100.0
Total	155		65		30	

[1/] Three flocks seen under good conditions were omitted from the table because of incomplete data.

[2/] See page 5 for definition of conditions and explanation of calculations.

Time of Day

It is the general belief amongst Hawaiian fishermen that more bird flocks are to be potted early in the morning and in late afternoon than during the middle daylight hours. This elief is borne out by the numbers sighted per hour on GILBERT cruise 11 during April 1953, which are plotted in figure 6. There was a peak between 7 and 8 a.m. and a decline until noon, with an increase to another peak between 2 and 4 p.m.

This daily pattern of behavior is not constant, however, because on GILBERT cruise 13 n June 1953 the greatest number of flocks was sighted between 11 a.m. and noon, with goodly numbers sighted at all hours between 7 a.m. and 5 p.m. (fig. 6). The distribution continued to be about the same during the three Smith cruises in the fall months. We have no knowledge at this time as to why this pattern changed after April. It might have been caused by a change in he behavior either of the birds or of the fish. We do note that the schools seen in April were predominantly small schools of small fish, whereas those seen during the June and autumn cruises included more large fish.

Differences Among Observers

The maintenance of a continuous watch implies maintaining it at constant efficiency, and of course this was essential in the study. The tedium and eye strain of searching and the normal ship's routine of activities require changing the fishermen on watch every 2 hours. Furthermore, for various reasons there were changes in the crew list between cruises and even in the midst of cruises. Consequently it is vital to our study to determine whether the different fishermen observed uniformly.

Fortunately it appears that the numbers of schools sighted by the different fishermen are sufficiently uniform to indicate that we have been maintaining essentially a constant watch. In able 9 we list the numbers sighted by various fishermen according to distance from the vessel nd cruises in which they participated. Fishermen B, E, F, and H were considered the most xperienced. There appears to be no tendency for any one man to sight flocks closer or farther han the others. In particular areas on different cruises there is a tendency for certain men to ight more flocks, but it is to be noticed that fisherman E, who sighted the most flocks on GILBERT 11 in Area I, sighted the least on GILBERT 13 in Areas II, III, and IV, and fisherman

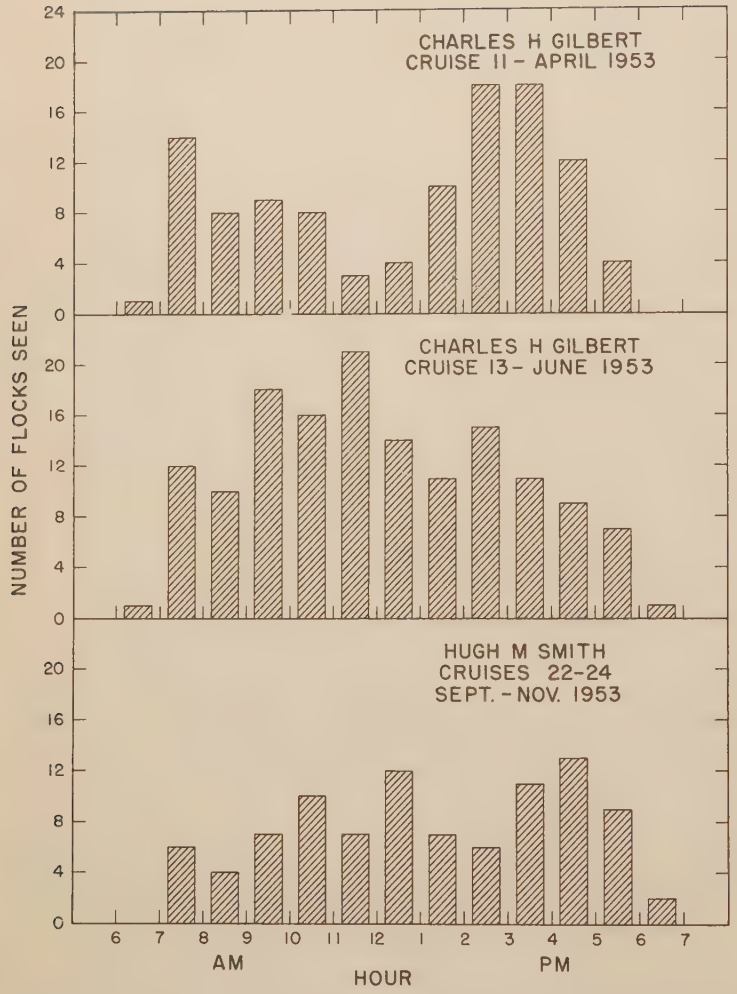

Figure 6.--Diurnal variation in the frequency of sightings of bird flocks on GILBERT cruises 11 and 13 and SMITH cruises 22-24.

D, who sighted the least on GILBERT 11 in Areas I and II, sighted the most on GILBERT 13 in Area I. We believe that the variations in the total number sighted indicate no difference in effort, the differences being due rather to a somewhat greater than random variation in conditions. This may well occur, because groups of schools were sometimes sighted in quick succession in a small area. We conclude that these differences between observers are not significant and that the changes in personnel did not affect our results.

EVALUATION OF AIRPLANE SCOUTING

With the exception of Flight No. 2, on which eight fish schools were sighted, the results of the six flights were very poor from the standpoint of giving information on the abundance and distribution of skipjack in the Hawaiian area. Although the flights were made at different times of the year and covered periods of relatively heavy skipjack catches by the commercial fleet as well as the off-season months, the aerial survey results did not indicate such seasonal fluctuations (table 10). On the contrary, the largest number (8) of fish schools and bird flocks seen was during the flight in December 1952, a month of low skipjack catch in the Hawaiian fishery. The flight made during June 1953, a month of good skipjack catches, resulted in the sighting of only one bird flock. Furthermore, on all flights the number of flocks seen per 100 miles was far less than the number seen from our vessel scouting the same area simultaneously.

It appears that our aerial scouting was greatly affected by weather and sea conditions. For example, during Flight No. 2 the weather was excellent with superb visibility. The sea was flat calm with only breeze patches in most areas. This flight resulted in the sighting of four schools (three skipjack and one yellowfin) not associated with any birds and four other schools attended by birds. Two of the flights (Flights 1 and 3) were made under generally adverse scouting conditions, with occasional rain squalls, overcast skies, and poor visibility. The seas were choppy with numerous white caps, making observations difficult. Flight No. 1 resulted in the sighting of three flocks, while on Flight No. 3 only one flock was seen. Somewhat more discouraging are the poor results of the last three flights (4, 5, and 6) which were made in typical, that is generally good, weather with moderately choppy seas. Only eight flocks were seen on all three flights. On these same three days the GILBERT was scouting and reported 31 flocks.

Table 9.--Number and distance of flocks sighted by various fishermen

CHG 11 - Area I - 4/25-28						CHG 11 - Area II - 4/11-21				
Miles from Vessel	Fishermen					Miles from Vessel	Fishermen			
	A	B	C	D	E		C	D	F	G
1/4 - 1	2	1	4	1	8	1/4 - 1	5	2	5	7
1-1/4 - 2	6	4	4	3	8	1-1/4 - 2	1	4	13	9
2-1/4 - 3	1	1	0	1	1	2-1/4 - 3	3	3	2	3
3-1/4 - 4	0	1	0	0	0	3-1/4 - 4	0	0	2	1
Distance unrecorded	0	0	0	1	0	Distance unrecorded	0	0	0	0
Total	9	7	8	6	17	Total	9	9	22	20

CHG 13 - Area I - 6/13-16					CHG 13 - Areas II, III IV - 6/22-7/11				
Miles from Vessel	Fishermen				Miles from Vessel	Fishermen			
	B	D	E	F		B	E	F	H
1/4 - 1	5	15	7	3	1/4 - 1	4	4	4	5
1-1/4 - 2	4	3	5	6	1-1/4 - 2	19	7	19	17
2-1/4 - 3	1	0	1	0	2-1/4 - 3	5	2	2	5
3-1/4 - 4	0	0	0	1	3-1/4 - 4	0	0	0	0
Distance unrecorded	0	0	0	0	Distance unrecorded	0	1	1	0
Total	10	18	13	10	Total	28	14	26	27

In addition to the weather conditions, the visibility of the bird flocks which we are using as indicators greatly influenced our results. In the Hawaiian area the sea birds are mostly dark-plumaged and difficult to see against the background of the water. This effect is noticeable from the vessel but is minimized by observing from close to the water where the birds are seen against the sky. On the other hand, the difficulty is so great when observing from the plane that we saw bird flocks of different composition than those seen from the vessel. Of 15 flocks sighted during the 6 flights, 11 consisted predominantly or solely of white boobies, while only 4 flocks were of the dark-colored terns and shearwaters. Vessel scouting at nearly the same times produced sightings of 39 bird flocks, of which only 1 was white boobies; 19 contained no white-plumaged birds at all, while the remaining 19 contained a few white birds. We conclude that many flocks of dark-colored birds were overlooked by the observers on the plane.

This is surprising because it is easy to see individual flying fish from the plane at an altitude of 1,000 feet or more. When they leave the water they attract attention by the glitter of the sun on their wet bodies. However, they were not seen beyond about 1,600 feet from the track of the plane and most of them between 200 and 400 feet. During the last flight (Flight No. 6, June 15, 1953, at 800 feet altitude) the angles from vertical were recorded for 152 objects sighted, which were mostly flying fish and scattered birds. Tabulation showed that 52 percent were between 15° and 30° from vertical on both sides of the plane. Between 0° (directly beneath the plane) and 15° there were 17 percent, between 30° and 45°, 13 percent, and between 45° and 60°, 18 percent of the total sightings. The small percentage recorded directly below the plane was probably a result of its being somewhat of a "blind spot" to the observers, who experienced some difficulty in vertical scanning. Thus for objects of this kind the effective scanning radius of the plane is only about 1/3 mile or less. Of course, large flocks of birds might be seen at greater distances, but we saw so few that we have no estimate of how far they might be seen.

Table 10.--Comparison of plane and vessel scouting

Plane						Vessel				
Flight No.	Date	Hours Scouted	Miles scouted	Flocks and schools seen		Date	Hours scouted	Miles scouted	Flocks and schools seen	
				Total	Per 100 miles				Total	Per 100 miles
1	11/14/52	3.6	355	3	0.85	11/13/52	8	75	2	2.67
2	12/12/52	4.7	450	8	1.78	12/12/52	10	90	5	5.56
3	12/18/52	4.7	470	1	0.21	12/18/52	10.5	85	3	3.53
4	3/28/53	4.4	430	4	0.93	3/27/53[1/]	7.0	50	6	12.00
5	4/27/53	4.7	440	3	0.68	4/27/53	11.7	90	12	13.33
6	6/15/53	4.5	440	1	0.23	6/15/53	10.8	90	13	14.44

[1/] Incidental scouting while vessel was enroute to hydrographic section in Kaiwi Channel--some flocks seen at station.

Another factor which may lessen the efficiency of the plane is the tendency of the bird flocks to assemble and disperse while following a school. Hence, more schools will be seen if an area is watched for a longer time. If we take 1/3 mile as the effective scanning radius of the plane, as suggested by the observations in the preceding paragraph, it will be possible to observe a particular spot of ocean not more than the time required to fly 2/3 of a mile, or 24 seconds in a plane flying at 100 knots. On the other hand, a similarly effective scanning radius for the vessel may be 2 miles, which would permit watching a spot up to 24 minutes from a vessel moving at 10 knots.

Despite the small number of flocks and schools sighted on most flights, it is significant that four of the eight fish schools seen on Flight No. 2 were not accompanied by birds. Such a discovery of an unaccompanied fish school was never made from the vessels during the following year. This suggests that when conditions are right for fish schools to be spotted directly (as they were on Flight No. 2), the airplane is effective in locating them, as has been reported by Harrison (1931) and Cushing et al. (1952). However, when the sea has white caps, as it usually does around Hawaii, and the fish schools must be located by the accompanying birds, the airplane is not as effective as a vessel.

MOVEMENT OF SKIPJACK SCHOOLS

The seasonal appearance and disappearance of the skipjack schools as well as the seasonal change in the average size suggest that the species is migratory, coming and going with the seasons, and that there may be different populations moving through the area at different times. Our data offer little conclusive evidence of any migrations of the skipjack but do provide some information regarding the seasonal distribution of schools and the movements of schools during limited periods of observations.

Perhaps most conclusive is the seasonal shift in abundance between the northeast and southwest sectors off Oahu. The results of the standardized scouting from February to November (table 11) indicate that in the northeast sector the skipjack were less abundant in February and during the fall months of September through November than in April and June. This is the kind of change in distribution that might be expected if the fish move south in the winter, and the absence of schools in the northeast sector during the 4 days of scouting in November suggests that Hawaii may be near the northern limit of the skipjack in the winter months.

There also are shifts of schools from one locality to another around the islands during the fishing season. This is well known to the fishermen and is evident in the statistics of fluctuating catch by area. It is also indicated in our scouting data by the very low number of schools per day seen in Area III during June, when they were abundant in other localities. Our data are too

icant to provide any further information about these shifts, but since they do occur, it clearly is ecessary to plan the scouting to include a considerable area around the islands if our results are o be comparable with those of the local fishing fleet.

Table 11.--Abundance of skipjack schools by area

Cruise	Month	Number of skipjack schools per 100 miles scouted			
		Northeast sector	Southwest sector		
		Area I	Area II	Area III	Area IV
GILBERT 7	Feb.	1.8[1/]	5.8	8.1	
GILBERT 11	April	13.1	8.3		
GILBERT 13	June	14.4	7.8	1.7	8.9
SMITH 22	Sept.	2.4		4.8	
SMITH 23	Oct.	0.5		3.3	
SMITH 24	Nov.	0.0		1.6	

[1/] The scouting of the northeast sector during GILBERT cruise 7 was not on the regular arms of Area I (see fig. 2)

When the cross-like patterns of scouting were laid out for the February, April, and June cruises, it was thought that any concerted movement of schools through the area might be detectable by a "Doppler effect" and by means of vector analysis the direction of movement might be determined. The number of schools sighted on certain arms of the areas scouted do indeed suggest a Doppler effect (fig. 7). For example, in Area I during April we found 8 schools while traveling west and only 3 on our return towards the east. On the south arm we found 12 schools while heading south and 7 while proceeding back toward the center. Similar results were obtained in the south and west arms of Area II in April, and during June on the east and west arms of Area I, on the west arm of Area II, and on the west arm of Area IV. These all show that more schools were sighted on runs toward the south and west than were seen on the reciprocal runs toward the north and east. If this could be ascribed to a Doppler effect, then the schools would have been moving toward the northeast; a vessel meeting the schools would encounter more of them than a vessel proceeding in the same direction as the schools.

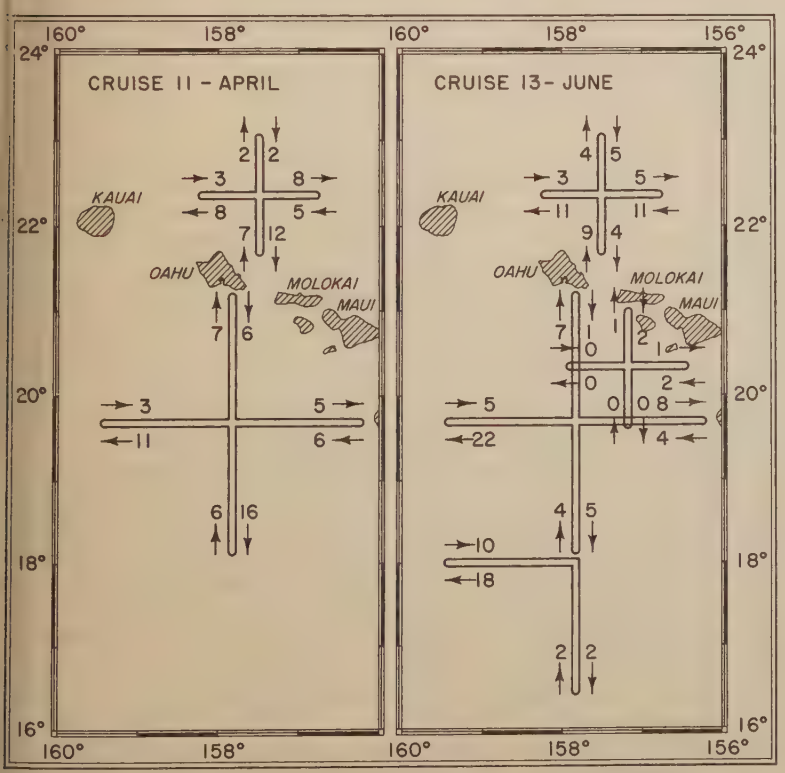

Figure 7.--Numbers of schools seen during systematic scouting on the April and June cruises of the CHARLES H. GILBERT.

However, the weather is definitely a factor here because of the prevailing northeasterly winds, which made the scouting conditions poorer on the runs toward the east and, to a lesser

degree, on those toward the north. It has previously been pointed out that almost all of the scouting conditions classified as poor were encountered on runs toward the east and the highest proportion of good conditions was found on the runs towards the west. Since the weather was quite steady, we have no way of separating a possible Doppler effect from the weather effect with these data.

But we do have direct observations on the schools, which frequently moved considerable distances while they were being observed from the ship. It is reasonable to assume that any collective migration of these schools would be evident in the average movement of the individual schools during the 5 to 15 minutes for which they were watched. (It will be recalled that when schools were sighted, a minute-by-minute record of the ship's course and the relative bearing and distance of the school was maintained. This permits reconstructing a track chart of the school while it was under observation, though it is subject to some inaccuracies due to the problems of estimating distance.) When the movements of these schools during the first 10 minutes of observation are plotted, it is found that less than half of them show definite movement. Usually the schools were milling about in one place, but at times they were moving and sometimes at speeds of 10 to 15 knots. When we plot the movement of the schools which were seen to move during a 10-minute period on all runs where the relative numbers of schools suggest the Doppler effect (fig. 8), we find that the movement of the schools is almost a random one except on the south arm of Area II in April, where most of the schools were moving southwesterly, on the east and the west arms of Area I in June, where they were moving westerly, and on the west arm of Area IV, cruise 13, where they were moving northerly. Since the apparent Doppler effect suggests a northeasterly movement and there is not a single instance of the concerted movement of the schools while under observation substantiating this, we conclude that the apparent Doppler effect is due entirely to weather and to the inevitable fluctuations of rather small numbers.

The plots of figure 8 do suggest that at times the movement of schools is concerted rather than random, and this may be further evidence of the tendency of schools to vacate or appear in limited localities.

ABUNDANCE OF SCHOOLS IN RELATION TO LAND AND TO THE FISHING AREA OF THE FLEET

The Hawaiian skipjack fleet habitually operates within 20 miles of land and from 1948 to 1952 took 74.5 percent of its catch in that zone (fig. 9). However, this does not mean that the vessels operate within 20 miles of port because some may range much farther by operating along other than their home islands. Since the fishermen can be expected to know where the fish are easiest to locate and can easily range 100 miles or more from land, the fact that most of the catch came from within 20 miles might mean that skipjack are more abundant in this zone. Moreover, such abundance would be expected because of general observations that fish of many species are more abundant near the reef.

However, during our spring scouting more tuna schools per day were seen outside the zone extending to 19 miles from shore (table 12). They were most abundant in the zone from 20 to 39 miles from shore, but to the limit of scouting, about 300 miles south of Oahu, they remained slightly more abundant than in the inshore zone during most cruises. These small differences are probably not significant, because much of the inshore scouting was performed on runs to hydrographic stations or while on other missions when scouting was incidental. Furthermore, the area scouted were mostly between Oahu and Maui, or north and south of these islands. This area is near the center of the fishery but is not representative of the entire fishing area in the zones specified. We consider the data to indicate that the schools were nearly randomly distributed in the area scouted but with local changes as indicated by the scarcity of schools in Area III in June, and with a shift in relative abundance between the north and south sides of the islands.

After the discovery that the schools were abundant beyond the customary range of the fleet and probably beyond the range of our spring scouting, we planned our fall scouting to encompass two larger sectors, one northeast and one southwest of Oahu (figs. 3 and 10). In these sectors scouting was done out to 350 miles southwest and to 230 miles northeast of Oahu. On all three of the cruises, with the exception of one station, the schools were about equally abundant

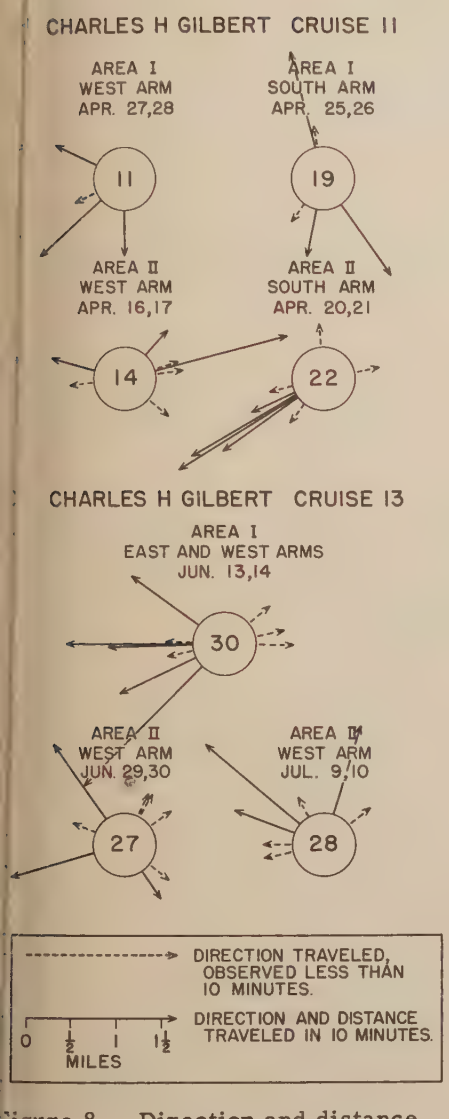

Figure 8.--Direction and distance moved in 10 minutes by schools seen on runs where a Doppler effect was suspected during the April and June cruises. The number in the center is the total number of schools seen; the number of arrows indicates the number of schools which moved. Distances are indicated from the circle, not its center.

in all parts of each sector, but they were consistently less abundant to the northeast. Also, the abundance decreased from month to month.

The exceptional station where more schools were sighted on the September and October cruises was located about 80 miles west of Hawaii and 110 miles south of Oahu. The abundance of tuna here seems the more significant because it is near an eddy which is indicated in our preliminary analysis of oceanographic observations. This eddy, which is now being made the subject of more detailed study, is a counterclockwise one, in the center of which the thermocline rises to less than 100 feet of the surface. It is suspected that this eddy may somewhat enrich the waters and indirectly create more food for the skipjack.

SEASONAL TREND

The seasonal trend in the landings of skipjack is fairly constant and is well known to everyone in the local fishing industry. With minor variations, the low landings of the winter months increase gradually to a peak in the summer and decline again to a low in the winter. The pattern during 1953 was nearly typical, with a peak in June and a secondary peak in August. Therefore, when our scouting results indicate a markedly different seasonal pattern of abundance (fig. 11), with a peak in April and much lower abundance during the fall months, it would appear to be a matter for further study.

First, we must consider the reliability of the estimates of abundance from our scouting results, and since in most cases a considerable amount of scouting was done, the question appears to become one of whether the areas covered by our scouting were representative of the areas being fished by the fleet. The cruises from which we have scouting data have varied considerably in length, the scouting frequently has been incidental to other operations, and the areas covered have varied considerably among cruises. However, on the cruises in February, April, June, September, October, and November scouting was the major objective and large areas were covered. This scouting extended far outside the range of the fleet, but it revealed a fairly uniform geographic distribution of schools and the results should be similar to the experience of the fleet. Also, the seasonal pattern indicated by these major cruises is supported by the scouting results of GILBERT cruises 3, 6, 8, and 12, during which scouting was incidental and much more restricted in area.

Therefore, it seems clear that our scouting results are representative, and yet they differ markedly from the trends in the commercial catch. The principal and most significant difference is the peak in abundance indicated by the April scouting, which does not correspond to a peak in the catch, and for an explanation we turn to more detailed data from the commercial fishery itself during the periods of GILBERT cruises 11 and 13 in April and June. Table 13 is a summary of data from interviews with captains obtained by the Division of Fish and Game, Board of Commissioners of Agriculture and Forestry, Territory of Hawaii. These records show that the commercial fishermen also saw slightly more schools per day during April, but these schools were mostly small

fish and a much smaller percentage of them was fished by the fishermen. We suspect that they were not fished partly because they were small fish and also partly because they may have been smaller and wilder schools. In either case the fishermen are reluctant to waste bait if there is a fair possibility of encountering a big school of large fish during the next few hours. The fishermen also avoid small fish, even though they sell them for the same price per pound, because the buyers prefer the larger fish and threaten to pay less or not buy if large quantities of small fish are landed.

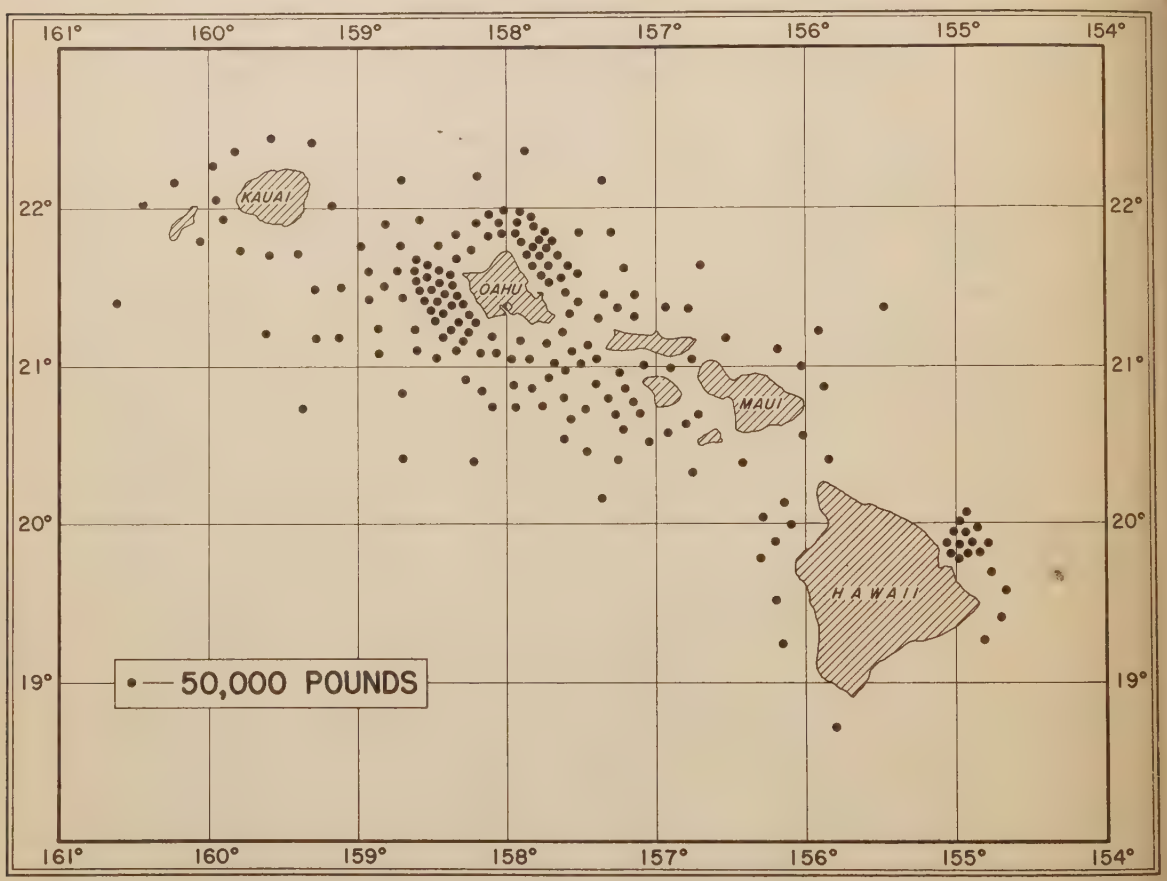

Figure 9.--Location of the average year's catch of skipjack from 1948 to 1952. Data compiled from records of the Division of Fish and Game, Board of Commissioners of Agriculture and Forestry, Territory of Hawaii.

In spite of seeing fewer schools per day in June, the fishermen were much more successful, as is indicated by the catch per day in table 13. Thus the success of the fishery depends on the size and behavior of the fish as well as their abundance, and there are seasonal cycles in all of these factors.

RESULTS OF LIVE BAIT FISHING

The amount of live bait fishing which we were able to accomplish on our cruises was limited, but in general our experience was similar to that of the commercial fishermen during the same period in that we encountered smaller fish during the spring months and larger ones during the autumn.

Table 12.--Abundance of bird flocks in relation to distance from land[1/]

Cruise	Date scouted 1953	Distance (miles)	Hours scouted	Number of flocks sighted	Number of flocks per 10-hour day
GILBERT 7	Jan. 26-Feb. 14	0 - 19	76.0	28	3.7
		20 - 39	22.0	18	8.2
		40 - 59	18.5	21	11.4
		over 60	28.5	6	2.1
GILBERT 11	Mar. 27-Apr. 29	0 - 19	60.5	52	8.6
		20 - 39	39.0	36	9.2
		40 - 59	32.0	22	6.9
		over 60	68.0	48	7.1
GILBERT 13	June 5-July 5	0 - 19	90.0	41	4.6
		20 - 39	44.0	34	7.7
		40 - 59	38.5	20	5.2
		over 60	106.0	85	8.0
Sum		0 - 19	226.5	121	5.34
		20 - 39	105.0	88	8.38
		40 - 59	89.0	63	7.08
		over 60	202.5	139	6.86

[1/] Includes incidental as well as systematic scouting results.

Live bait fishing by itself was never a major objective of the cruises. It was carried on n conjunction with tests of tuna attractants, which were usually performed in the calm leeward vaters where the tuna were easy to observe. On scouting runs live bait was available only a small part of the time and it was used to sample as many schools as possible.

Our relative success in fishing schools may be judged only by the percentage of schools rom which we caught fish. In no instance was our catch indicative of what might have been taken by a commercial fisherman, because we regularly stopped fishing as soon as a sample of the chool was obtained. Of a total of 83 schools chummed, 36 or 43 percent were successfully ished (table 14). The failures were those which did not respond at all or which did not approach he vessel after rising to the surface for the chum. No consideration was given the number of asses made in the school or the number of fish taken. There were some variations in the per-entage of success during the various cruises, but the numbers are so small that the differences re not statistically significant.

Our sampling bore out what is common knowledge among the fishermen--that the skipjack chool by sizes. The length and weight frequencies of skipjack taken are given in table 15. Many f our samples are too small to be indicative of the range of sizes in the school, but in some of he schools of small fish from which adequate samples were obtained the range was as rom 2-3/4 to 3-3/4 pounds (on April 28 and July 5). Other schools were more mixed, the one ished on June 8 ranging from about 2-1/4 to 9-1/2 pounds and another, on June 9, from about -3/4 to 12 pounds. The larger fish were always by themselves, and with an average size of bout 20 pounds they commonly included a range of 10 or 12 pounds. Brock (1954) also found kipjack to school by sizes, and he reported the mean range in length of fish in a school (based n 120 school samples taken in 1950) to be 11.3 cm. compared to the range of 47 cm. for fish n the landings as a whole.

The proportion of schools of large skipjack (over 10 pounds) which we fished appears to be similar to that reported by the fishery, except during June [6/], when only one of the eight schools we sampled was large. During April one of nine schools was large, and during Septembe all of the six schools sampled were composed of large fish.

SUMMARY

Three scouting cruises of the CHARLES H. GILBERT were made in February, April, and June 1953. These were followed by three cruises of the HUGH M. SMITH in September, October and November 1953. Cruises primarily for other purposes but on which some scouting was done were made in November and December 1952, and in late February and May 1953.

Six scouting flights were made in U. S. Navy PBY amphibian planes between November 1952 and June 1953.

Skipjack schools are located almost entirely by accompanying bird flocks, which frequentl by their behavior indicate the size of schools and species of the fish. The flocks are chiefly composed of dark-colored terns and shearwaters.

Bird flocks were located up to 4 miles from the vessel, but most were seen within 2 miles. The average proportion spotted at 4 miles was only 0.2 percent of the schools estimated to be present. At 2 miles only 5.9 percent had been seen and at 1 mile 42.4 percent. Flocks were seen at nearly random bearings in the quadrants forward of the vessel.

Few were seen astern of the vessel in the spring scouting but after instructions to search astern as much as ahead, in the fall scouting the fishermen located 22 percent more flocks.

Larger bird flocks were seen at greater distances from the vessel.

Poor scouting conditions were mostly due to spray over the bridge, which interfered with the use of binoculars. Thirty-eight percent less schools per hour were seen under poor conditions than under good and none were seen beyond 2 miles under poor conditions.

The hours of the day during which most flocks were seen varied somewhat with the season. In April more were spotted between 7 and 8 a.m. and between 2 and 4 p.m.; in June most between 9 a.m. and noon; during the autumn the distribution was nearly random.

A fairly constant scouting efficiency was maintained despite frequent changes in personnel.

Airplane scouting revealed far fewer fish schools per unit of distance than vessel scouting. The principal reasons probably are the prevailing choppiness of Hawaiian waters and the difficulty of locating dark-colored birds against the background of the ocean.

Skipjack schools were more abundant northeast than southwest of the islands in April and June. In February, September, October, and November they were more abundant to the southwest, and in November none were seen in 4 days of scouting to the northeast. This suggests a seasonal migration.

The movements of schools, while being observed from the vessel, suggested in some cases a concerted movement which might lead to local abundance or scarcity, but there was no evidence of a general movement of the schools sufficient to cause a "Doppler effect".

The Hawaiian skipjack fleet obtained three-fourths of its catch from 1948 to 1952 within 20 miles of land, but both our spring and fall scouting indicated that skipjack schools were about equally abundant out several hundred miles to the limit of scouting, except for the difference between the northeast and southwest sectors, and except for a single station where on two of the three fall cruises substantially greater numbers of schools were located.

[6/] At this time the catch of the fishery was about 93 percent large fish.

This exceptional station was located in an area where oceanographic studies indicate upwelling may occur, which would enrich the water and provide more food for the skipjack. A more intensive study in this area will be made.

The seasonal peak in April of the number of schools sighted per day did not correspond with the summer peak in the catch of the fishery. This was due to a predominance in April of schools of smaller fish, which the fleet took in markedly less quantity than the fewer larger fish found in the summer months.

Forty-three percent of the fish schools which were approached and chummed with live bait came close enough to the vessel for some fish to take the hook.

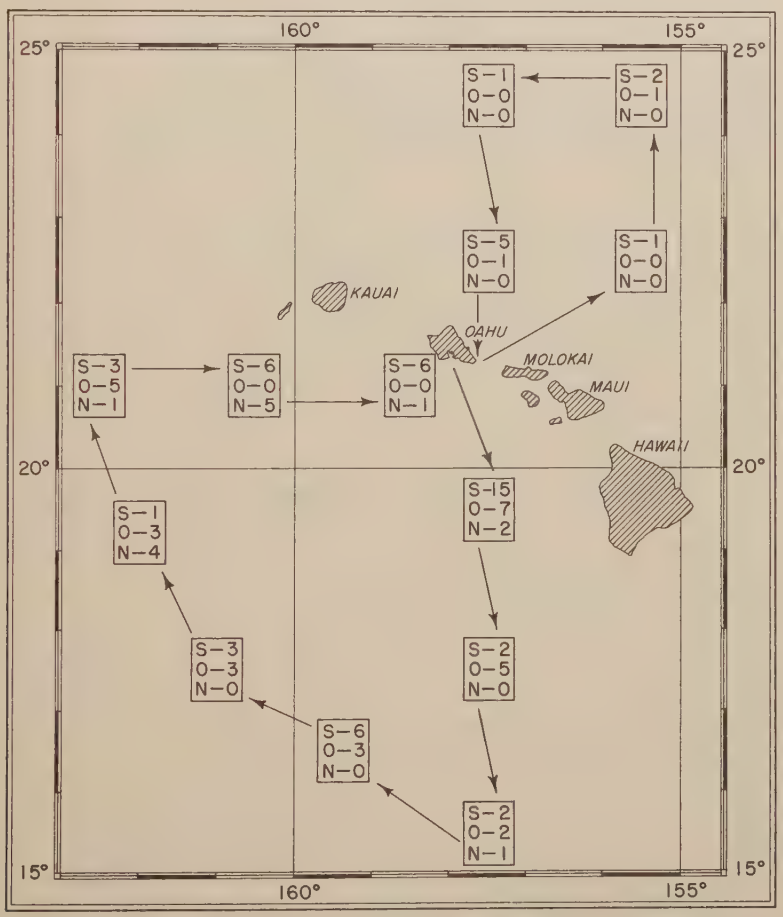

Figure 10.--Number of schools sighted on the autumn cruises of the HUGH M. SMITH. From top to bottom, cruise 22 in September, 23 in October, and 24 in November.

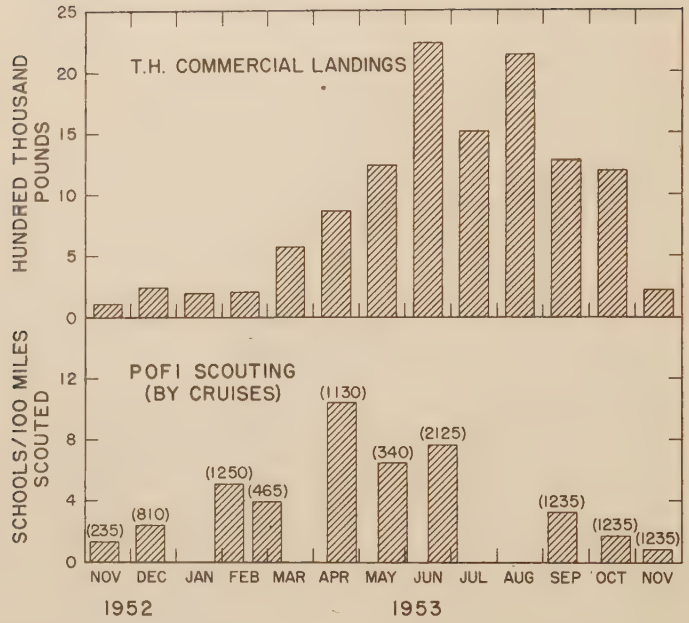

Figure 11.--Seasonal distribution of skipjack school sightings on POFI cruises compared with monthly landings of the commercial fishery. Upper--landings by months from statistics of the Division of Fish and Game, Board of Commissioners of Agriculture and Forestry, Territory of Hawaii; lower--numbers of schools sighted per 100 miles scouted, by cruises. The figures in parentheses are the total number of miles scouted on each cruise.

Table 13.--Summary of results of commercial fishing during periods of GILBERT cruises 11 and 13[1/]

Period	Apr. 13-Apr. 28	June 8-July 11
Number of boat-days	18	83
Number of schools sighted but not fished		
Small fish	47	25
Large fish	3	41
Size undetermined	0	1
Total	50	67
Number of schools fished		
Small fish	13	22
Large fish	20	238
Size unrecorded	0	12
Total	33	272
Percent of schools fished	40	80
Average production per school (pounds)	1,549	2,096
Number of schools seen per day	4.6	4.0
Average catch per boat-day[2/]	2,406	6,743
Percent of fish larger than 10 pounds in catch[2/]	63	93

1/ From interview records provided by the Territory of Hawaii, Division of Fish and Game.

2/ Based on 41 boat-days between April 12 and May 2, and 88 boat-days between June 7 and July 11.

Table 14.--Results of live bait fishing

Cruise	Total number of schools fished	Number successes		Number failures	
		Skipjack[1/]	Others	Skipjack	Others[2/]
GILBERT 7	10	1	0	4	5
GILBERT 11	19	9	1	5	4
GILBERT 12	19	4	3	4	8
GILBERT 13	17	8	0	2	7
SMITH 22	16	6	4	4	2
SMITH 23[3/]	2	0	0	0	2
Total	83	28	8	19	28

[1/] Includes mixed schools of skipjack and other tunas.

[2/] Unidentified schools, some of which may have been skipjack.

[3/] The 2 schools in this cruise were chummed first with artificial bait and subsequently with live bait.

Table 15.--Length-frequencies of skipjack taken by live bait fishing (each school tabulated separately)

Length (cm.)	Corresponding weight (lbs.)	C. H. GILBERT 11									C.H.GILBERT 12				C. H. GILBERT 13								H. M. SMITH 22						C.H.GILBERT 7
		April									May	June			June						July		Sept.						February
		11	12	12	20	25	26	26	26	28	12	1	1	1	8	8	9	24	25	29	5	6	5	7	12	14	17	18	2
30	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
36	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
39	2.5	-	1	-	-	-	-	-	-	-	3	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-
40	-	-	2	-	-	-	-	3	1	2	3	-	-	-	-	-	-	1	11	-	5	2	-	-	-	-	-	-	-
41	3.0	-	4	-	-	3	-	3	-	16	8	-	-	-	-	-	-	-	13	-	24	11	-	-	-	-	-	-	-
42	-	-	7	-	-	5	-	3	-	28	11	-	1	-	-	1	-	-	21	-	25	26	-	-	-	-	-	-	-
43	-	-	1	-	-	-	-	1	-	8	-	-	1	1	-	2	-	-	6	-	6	13	-	-	-	-	-	-	-
44	-	-	-	-	-	2	-	-	-	2	-	-	1	1	-	6	1	3	3	-	-	5	-	-	-	-	-	-	-
45	4.0	-	-	-	-	-	-	-	-	-	-	1	-	1	1	5	4	4	1	-	-	1	-	-	-	-	-	-	-
46	-	-	-	-	-	-	1	-	-	-	-	3	1	1	1	16	4	8	-	-	-	1	-	-	-	-	-	-	2
47	-	-	-	-	-	-	-	-	-	-	-	1	1	2	4	14	3	6	-	-	-	-	-	-	-	-	-	-	1
48	5.0	-	-	-	-	-	-	-	-	-	-	1	-	-	2	16	8	15	-	-	-	-	-	-	-	-	-	-	-
49	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	20	5	10	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	13	6	3	-	-	-	-	-	-	-	-	-	-	-
51	6.0	-	-	4	-	-	-	-	-	-	-	-	-	-	-	9	7	1	-	-	-	-	-	-	-	-	-	-	1
52	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	7	6	1	-	-	-	-	-	-	-	-	-	-	-
53	7.0	-	-	2	-	-	1	-	-	-	-	-	-	-	-	1	2	2	-	-	-	-	-	-	-	-	-	-	-
54	-	-	-	3	-	-	1	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-
55	8.0	-	-	4	-	-	1	-	-	-	-	-	-	-	-	2	5	1	-	-	-	-	-	-	-	-	-	-	-
56	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
57	9.0	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-
58	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	2	3	-	-	-	-	-	-	-	-	-	-	-	-
59	10.0	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
60	10.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-

Table 15.--Length-frequencies of skipjack taken by live bait fishing (each school tabulated separately) - Continued

Length (cm.)	Corresponding weight (lbs.)	C. H. GILBERT 11									C. H. GILBERT 12				C. H. GILBERT 13								H. M. SMITH 22						C. H. GILBERT 7
		April									May	June			June					July			Sept.						February
		11	12	12	20	25	26	26	26	28	12	1	1	1	8	8	9	24	25	29	5	6	5	7	12	14	17	18	2
61	11.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
62	12.0	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
63	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
64	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
65	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
66	15.0	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	1	-	-	-	-
67	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-
68	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	2	1	4	-	-	1	-
69	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	1	3	4	1	-	-	-
70	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	2	8	5	-	2	3	-
71	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	6	12	10	2	1	3	-
72	20.0	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	2	32	7	6	2	3	-
73	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	3	23	4	2	1	7	-
74	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	3	21	2	2	1	19	-
75	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	7	1	1	2	8	-
76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	1	7	-
77	25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-
78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	6	-
79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
81	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-
82	30.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
83	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
84	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
85	35.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Measured:		60	16	25	1	10	7	10	1	56	25	6	5	6	8	115	71	57	55	53	60	60	19	114	40	14	10	68	4

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APPENDIX

Cruise itineraries. The dates given are only those on which some scouting was performed

CHARLES H. GILBERT cruise 3, 1952

November 11 Honolulu Harbor to Kaunakakai, Molokai, via Kaumalapau, Lanai. Tuna scouting and fishing enroute. Offshore work not possible because of rough seas.

November 12 Kaunakakai to Brown's Camp, Oahu, via Penguin Banks. Tuna scouting and fishing enroute.

November 13 Brown's Camp to Pearl Harbor. Tuna scouting and fishing 1-10 miles offshore between Kaena Point and Barbers Point, Oahu.

ITINERARY

CHARLES H. GILBERT cruise 6, 1952

December 9	Departed Honolulu for tuna scouting and fishing following a southerly course 102 miles offshore.
December 10	Tuna scouting and fishing easterly 115 miles to Kailua, and Kauna Pt., Hawaii. Night-baiting at Kailua.
December 11	Tuna scouting and fishing 2 to 10 miles offshore between Kailua and Kauna Pt., Hawaii. Night-baiting at Kealakekua Bay.
December 12	Tuna scouting and fishing 3 to 17 miles offshore between Kealakekua Bay and Kawaihae, Hawaii. Night-baiting at Kealakekua Bay.
December 13	Enroute to Hilo, Hawaii. Night-baiting at Hilo.
December 14	Tuna scouting and fishing 2 to 12 miles offshore between Hilo Bay and Cape Kumukahi, Hawaii. Night-baiting at Hilo.
December 15	Enroute to Kahului, Maui. Night-baiting at Kahului.
December 16	Enroute to Kaneohe Bay, Oahu. Night-baiting at Kaneohe Bay.
December 17	Enroute to Nawiliwili, Kauai. Night-baiting at Nawiliwili Bay.
December 18	Tuna scouting and fishing between Kauai and Niihau area. Night-baiting at Port Allen, Kauai.

CHARLES H. GILBERT cruise 7, 1953

January 26-28	Operated around Kaneohe Bay, testing scouting methods, and conducting diffusion tests of fluorescein introduced from moving vessel.
January 29-30	Scouted for fish along Kaneohe-Kahuku-Kaena shoreline of Oahu. Conducted sea tests of fluorescein-fish extract mixture; also bait tank aeration test.
February 2	Scouted part of west arm then returned to Hub II.
February 3	Scouted east arm of Area II to Kailua, Kona.
February 4	Scouted off Kailua and north to Keahole Pt. Attempted sound tests.
February 5	Scouted east arm to Hub II.
February 6	Scouted north arm of Area II to Oahu.
February 8	Scouted north arm to Hub II.
February 9-10	Scouted south arm of Area II.
February 11-13	Scouted, north, south, and east arms of Area III.
February 14	Returned to Pearl Harbor.

CHARLES H. GILBERT cruise 8, 1953

February 25	Left Waianae anchorage and sailed to Nawiliwili, Kauai. Ran from Nawiliwili to Port Allen and anchored there overnight. Mission: To test tuna attractants and to study live bait fishing techniques from the C. H. GILBERT.
February 26	Left Port Allen at 0640 and cruised off Kauai and Niihau throughout the day, anchoring off the lee of the island of Niihau.
February 27	Cruised throughout the day off Niihau and Kauai, starting for Pearl Harbor at dusk.
March 1	Departed Pearl Harbor for Kaumalapau, Lanai.
March 2	Left harbor on Lanai, going to Maalaea Bay on Maui to search for bait and to Lahaina, Maui.
March 3	Scouted for fish west of Lanai, tested artificial bait and hydrophone. Returned to Pearl Harbor at night.

CHARLES H. GILBERT cruise 11, 1953

March 27-28	Executed hydrographic section in Kaiwi Channel.
April 1-2	Executed hydrographic section.
April 8-9	Executed hydrographic section.
April 11-12	Scouted north arm, Area II.
April 14-15	Executed hydrographic section.
April 16-17	Scouted west arm, Area II.
April 18-19	Scouted east arm, Area II.
April 20-21	Scouted south arm, Area II.
April 22-23	Executed hydrographic section.
April 25-26	Scouted south and north arms, Area I.
April 27-28	Scouted east and west arms, Area I.
April 29-30	Executed hydrographic section.

CHARLES H. GILBERT cruise 12, 1953

May 11-13	Tested fish attractant solutions at sea.
June 1-3	Tested fish attractant solutions at sea.

CHARLES H. GILBERT cruise 13, 1953

June 4-5	Executed hydrographic section.
June 8-9	Tested chemical and visual fish attractants at sea.
June 11-12	Executed hydrographic section.
June 13-16	Scouted Area I.
June 18-19	Executed hydrographic section.
June 22-23	Scouted north and south arms, Area III.
June 24-25	Tested chemical and visual fish attractants at sea.
June 27-28	Scouted west and east arms, Area III.
June 29-30	Scouted west arm. Area II.
July 1	Scouted north arm, Area II to Honolulu.
July 3	Scouted north arm to Hub II.
July 4-6	Scouted east and south arms, Area II.
July 7-10	Scouted south and west arms, Area IV.
July 11	Scouted northward on south arm, Area II.
July 12	Returned to Pearl Harbor.

HUGH M. SMITH cruise 22, 1953

September 3-7	Scouted north and east of Oahu.
September 11-21	Scouted south and west of Oahu.

HUGH M. SMITH cruise 23, 1953

October 9-17	Scouted south and west of Oahu.
October 23-26	Scouted north and east of Oahu.

HUGH M. SMITH cruise 24, 1953

November 6-15	Scouted south and west of Oahu.
November 19-22	Scouted north and east of Oahu.

MID-PACIFIC OCEANOGRAPHY, PART VII
HAWAIIAN OFFSHORE WATERS
SEPTEMBER 1952 - AUGUST 1953

SPECIAL SCIENTIFIC REPORT: FISHERIES NO. 164

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Explanatory Note

The series embodies results of investigations, usually of restrict scope, intended to aid or direct management or utilization practices a as guides for administrative or legislative action. It is issued in limi quantities for the official use of Federal, State or cooperating Agenci and in processed form for economy and to avoid delay in publication.

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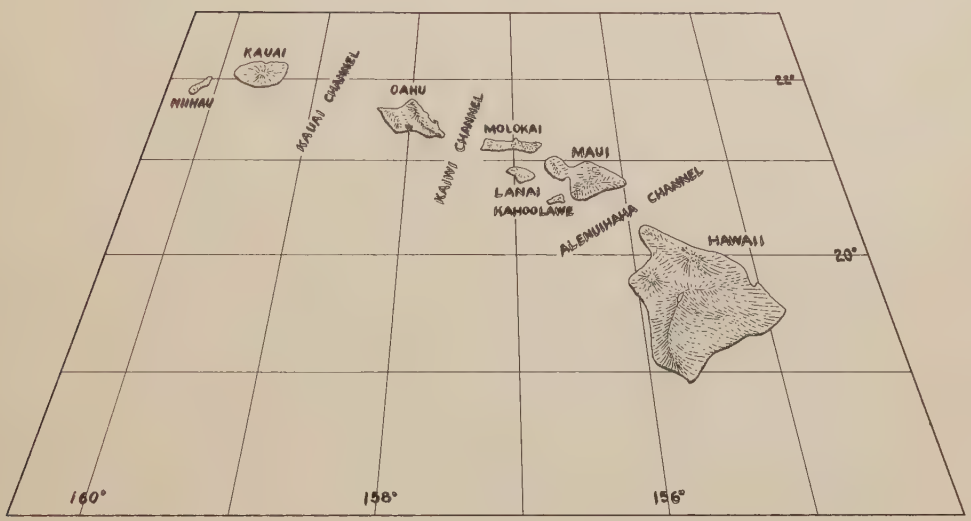

MID-PACIFIC OCEANOGRAPHY, PART VII

HAWAIIAN OFFSHORE WATERS

SEPTEMBER 1952 - AUGUST 1953

By

Gunter R. Seckel
Oceanographer
Pacific Oceanic Fishery Investigations
Honolulu, T. H.

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38. Phosphate-phosphorus distribution (µg-at/l) on the 26.5 sigma-t surface, H. M. Smith cruise 21. 61

In conjunction with the Pacific Oceanic Fishery Investigations' study of the tuna resources of the central Pacific, the hydrography of Hawaiian offshore waters was investigated during six oceanographic survey cruises. The first three of these, Hugh M. Smith cruises 1, 10, and 12 of December 1949, July 1951, and October 1951, were analyzed and recorded by McGary (1955). This report covers the remaining cruises 17, 20, and 21 of the Hugh M. Smith, which took place September 5 to September 15, 1952, February 25 to April 4, 1953, and August 4 to August 26, 1953 respectively. On Hugh M. Smith cruise 26, May and June 1954, additional oceanographic data were obtained in conjunction with skipjack scouting. These have not been analyzed in this report but are tabulated in the appendix.

The principal observations consisted of routine temperature and salinity sampling together with 200-meter oblique plankton hauls.[1/] Reliable inorganic phosphate-phosphorus data were obtained on cruise 21. The hydrographic data were collected and processed by methods described by Cromwell (1954), Stroup (1954), and McGary (1955).

Each cruise is discussed separately using a similar outline for each. A short summary of the cruise report is given first to indicate the nature of the observations. This is followed by a brief summary of the weather conditions encountered during the cruise.

The hydrographic data are then analyzed in two major groups, first those from the surface layer and then those from the subsurface layers. In the former the distributions of temperature, salinity, density, and surface geostrophic currents are emphasized. In the latter, attention is focused on the subsurface distribution of mass and how it contributes to the surface currents. The results of these analyses are then briefly summarized.

The report is concluded with a general summary in which the observations for each cruise are compared in order to point to possible seasonal variations. The tabulated observations for each cruise are included in the appendix.

The discussion is generally based on figures in which the variables are plotted and contoured on horizontal surfaces with points of observation marked by dots. As is generally the case, contour lines

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[1/] The plankton data for cruise 17 have been presented by King and Hida (1954). Those for cruises 20 and 21 are in preparation for separate publication.

represent an interpretation of the distribution of a variable and therefore may be open to dispute. The figures of this report are no exception. However, no observed points are violated and interpolations are generally linear except when boundary conditions suggest a deviation.

In order to obtain average values of temperature, salinity, etc., and their spatial trend, the survey region was subdivided into four areas. A line was drawn along the Hawaiian Island chain and another perpendicular to it through the western tip of Molokai island, as shown on figure 1. These lines divide the region into a windward (northeast) and a leeward (southwest) side with an east and a west section in each.

HUGH M. SMITH CRUISE 17

Summary Cruise Report

The cruise began September 5, 1952, and was completed September 15, 1952. Figure 1 shows the positions of the 31 hydrographic stations. Water samples were taken to a depth of 600 m. and oblique 200-m. zooplankton hauls were made on each station. Bathythermograph temperatures to 900 feet were obtained on each station and at 10-mile intervals. Synoptic weather observations were made four times daily and forwarded to the U. S. Weather Bureau.

Meteorological Conditions

Typical trade wind weather prevailed during the cruise period. Air temperatures were predominantly 77°F., with the exception of the portion southwest of the island chain, where the maximum deviations of $\pm 2^{\circ}$F. occurred and where the temperatures were generally slightly above 77°F. Winds were generally from $090^{\circ} \pm 20^{\circ}$T. with the exceptions of a few stations to the lee of the island chain where the deviation reached a maximum of $\pm 60^{\circ}$. No winds with a westerly component were observed. Speeds were generally between 15 and 20 knots, with extremes of 6 and 22 knots. No rain was encountered except on stations 8 and 14.

Surface Hydrography

The hydrographic conditions of the surface layer (upper 50 to 100 m.) are of importance since their variations have a primary

influence upon biological activities. Here the salinity and temperature, which determine the density of the water, show their greatest seasonal variations.

Besides effects due to the physical presence of the Hawaiian Islands in an ocean stream, one might expect the surface variables to be influenced by heavy precipitation on the windward slopes of the island mountains and subsequent runoff. The surface temperature is also expected to vary because of solar heating in shallow water and in wind-sheltered regions.

Temperature distribution

Surface bucket temperatures obtained at each bathythermograph position are contoured on figure 2 at intervals of 0.5°F. Surface temperatures averaged over the quadrants of the survey region are shown in table 1 together with the extreme temperatures encountered. Greatest deviations occurred on the leeward (southwest) side of the island chain. The maximum temperature of 80.5°F. was found off the west shore of the island of Hawaii. The lowest temperatures were found in an area centered at 20°N., 157°20'W., where the minimum was 74.8°F. (This type of cold temperature distribution was previously shown by McGary (1955) to be associated with a counterclockwise vortex.) On the windward (northeast) side of the island chain temperatures were more uniform, with two tongues of warmer water protruding north and northeastward of Molokai and Maui, respectively. On the windward side there was essentially no change in average temperature from east to west, whereas on the leeward side the average increased by approximately 1°F. in that direction.

Salinity distribution

Figure 3 shows the surface salinity distribution contoured at intervals of 0.05 °/oo. Averaged surface salinities are shown in table 1. Maximum salinities (greater than 35.2 °/oo) were encountered on the northern and eastern edges of the survey area and minimum salinities (less than 35 °/oo) off the west shore of Hawaii and along the southern edge of the survey area. A region of high-salinity water on the leeward side of the island chain is centered at approximately 19°45'N., 157°20'W., the same location as the temperature minimum.

Table 1.--Average surface temperatures, salinities, and densities in the quadrants of the survey region. H. M. Smith cruise 17

	Overall average	Northeast of island chain				Southwest of island chain			
		East	West	Overall	Extremes	East	West	Overall	Extremes
Temp. (°F.)	78.0	77.6	77.5	77.6	79.0 77.0	78.0	79.2	78.6	80.5 74.8
Salinity (°/oo)	35.12	35.18	35.15	35.15	35.33 35.05	35.08	35.05	35.06	35.28 34.95
Density (σ_t)	23.25	23.37	23.34	23.36	23.58 23.04	23.23	23.05	23.14	23.67 22.80

Density distribution

The surface density of sea water is a function of the independent variables temperature and salinity. Their relative importance can be judged when one considers that the change of surface density in the Hawaiian Islands region due to a 0.3 °/oo salinity decrease is approximately equivalent to a 1.6°F. temperature increase. Thus, changes in salinity as shown in table 1 are not negligible in their effect on the density.

Figure 4 shows the surface density distribution in units of sigma-t with contour intervals of 0.1. When compared with figures 2 and 3, it indicates that the main features of temperature and salinity had an additive effect upon the density distribution; that is, whenever the temperature was low, the salinity was high, and conversely low salinities corresponded with high temperatures.

Average surface sigma-t values are listed in table 1. The lowest densities occurred on station 1 and off the west shore of Hawaii. The densest water was found in a region centered at 20°N., 157°15'W. associated with the counterclockwise vortex. The average density increased from south to north and from west to east.

Surface circulation

It is not always easy or desirable to make direct current measurements in order to obtain the circulatory pattern of a region.

Local fluctuations may obscure the average circulation completely, especially when the observations are made over a short period of time. In one convenient method of indirect current measurement the difference of the vertical distribution of mass (specific volume) between two stations is used to calculate the component of the current vector normal to the line between the stations. There are some essential assumptions which must be satisfied. The region under consideration must be several degrees of latitude removed from the Equator, a steady state must exist (no accelerations), and dissipative forces such as friction must be negligibly small. Another problem in these computations is the proper choice of a reference level, the surface along which no component of gravity acts. It is usually assumed that at a depth where the specific volume change of the water between stations is small compared to that in the surface layers, the isobaric surface is "level", i.e. changes are so small that they will not materially change the computed currents in the surface layers. To be precise, the computed surface currents are relative to those at the reference level.[2/]

When the method of computing "relative currents," based on the "distribution of mass," is applied to the Hawaiian Islands region, it is assumed that the restrictions mentioned above hold. However, because of the boundary effect of the islands, the steady state and the friction assumptions may not be exactly satisfied, particularly in places of high current speeds. Distortions in the calculated circulation pattern may therefore exist, but they are not expected to materially change its principal features.

Figure 5 shows the geopotential topography[3/] in dynamic meters, of the sea surface referred to 600 m.[4/] The outstanding feature is the counterclockwise, rotary current motion or vortex centered at about 19°45'N., 157°20'W. with speeds on the order of 1 to 2 knots. There

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[2/] A more detailed, non-mathematical discussion can be found in Sverdrup et al. (1942:389-395).

[3/] Also referred to as geopotential surface, dynamic topography, dynamic heights, or dynamic height anomalies.

[4/] Strictly speaking the reference level in dynamic computations is an isobaric surface. However, under the assumptions used, this surface is so close to an isobathic surface that, for simplicity, meters will be used to designate the reference depth.

are two smaller, clockwise vortices, one off the west shore of the island of Hawaii and one northwest of the counterclockwise vortex. West of these vortices, a 0.2-knot current sets north and is deflected westward south of Kauai Channel.

On the windward side of the island chain the current pattern is weak except east of Hawaii Island, where a 1/2- to 1-knot current is setting south, and in the region northeast of Kauai, where a 1/2-knot current sets first southwest and then changes to west north of Kauai. The dynamic topography north of the island of Hawaii between 20° and 22°N. indicates a westerly setting drift from east of the survey region which is deflected to the south.

The geopotential topography both north and south of Kauai Channel indicates no transport of water through the channel but a flow normal to its axis in a westerly direction. In Alenuihaha Channel a slow current setting to the northeast is indicated.

Surface temperature, salinity, and density and the surface circulation

Figures 2, 3, 4, and 5 show that the major features of temperature, salinity, and density compare well with the dynamic topography, remembering that in the northern hemisphere the light water is to the right of the observer facing in the direction of the current (Sverdrup et al. 1942: 394). In the center of the counterclockwise vortex the temperature is low, the salinity high, and therefore the density is high. The two clockwise vortices are not as easily recognized from the surface distribution of variables, although the high temperatures west of Hawaii suggest one of them. The other vortex is located in the zone of high current shear between the counterclockwise vortex and the northerly drift.

The slow clockwise circulation about the island of Hawaii can also be inferred from the warmer and fresher inshore waters. According to the dynamic topography the tongues of warmer water protruding north and northeastward of the islands of Molokai and Maui do not indicate a flow of water in those directions as much as an intrusion of colder water north of Oahu and northeast of Alenuihaha Channel.

Thus, north and south of the portion of the island chain between Oahu and Maui, there is good agreement between the circulation patterns obtained from the surface density and from the dynamic topography. West of this region and northeast of Alenuihaha Channel there is a considerable difference. In the southwest part of the survey region and

northeast of Alenuihaha Channel the light water is actually to the left of the current direction; in the northwest part the direction of flow is perpendicular to that expected from the density distribution.

The over-all surface density distribution in the survey region leads to the assumption that the water generally flows in a southeasterly direction, which is contrary to the surface dynamic heights. These apparent discrepancies in the rule of direction of flow can be explained by considering the subsurface distribution of mass.

Subsurface Circulation

A qualitative picture of the three-dimensional subsurface circulation can be obtained by plotting variables on one of several systems of coordinates. Each of these presentations will illustrate features which are missed in others. The distribution of temperature, salinity, sigma-t, oxygen, phosphate, or depth can be presented on vertical planes (sections). A vertical section of sigma-t, for example, is most useful when it cuts the direction of flow at right angles. It then gives an indication of relative current speeds. The distribution of parameters can also be plotted on "horizontal" planes which are approximately parallel to the sea surface (surfaces of constant pressure or depth). This method is particularly useful in regions with a complex current system, such as is encountered in the vicinity of the Hawaiian Islands. Its shortcoming is that vertical gradients are not apparent.

A useful variation of either method is the use of one of the parameters as a coordinate. Such a parameter is the potential density, which is particularly useful since particle motion takes place along surfaces of constant potential density. (The potential density, approximately expressed in units of sigma-t, is the density a particle of water would have if brought to the surface without loss or gain of heat.) The deduction of the flow pattern from the distribution of variables on these "sigma-t surfaces" is generally known as isentropic analysis (Montgomery 1938).

On a horizontal frame of reference, then, one can plot the depth of a sigma-t surface and obtain its bathymetric chart. For these depths and on the same chart the salinity can then be plotted. Together, the isopleths of depth and salinity referred to a surface of constant sigma-t might give an indication of the direction of flow.

The isobaths are generally parallel to the flow, provided that the slopes of the sigma-t surfaces below are in the same direction. The

direction can be obtained by the use of the rule previously stated. Deep isobaths represent columns of lighter water below the surface and therefore will be to the right of an observer facing in the direction of flow.

Flow takes place along the sigma-t or quasi-isentropic surfaces (Sverdrup et al. 1942:414-416), across which mixing is at a minimum. Thus, identifying properties of a water mass, such as salinity and temperature, would be retained longest in the direction of flow or, conversely, the direction of flow would be along the minimum change of the identifying property such as salinity.

These principles will be used in an attempt to interpret the subsurface circulation.

Figure 6 shows the sigma-t distribution plotted on a vertical plane extending from west to east through stations 1, 10, 14, 22, 21, and 30. The dominating feature of the section is the wave-like distribution of sigma-t west of station 22. The rising isopleths east and west of station 14 are associated with the "doming" of the sigma-t surfaces which characterize the counterclockwise vortex mentioned before. The rule of direction of flow indicates a current setting north between stations 22 and 14 and one setting south between stations 14 and 10.

The section between stations 1 and 10 demonstrates that the surface density distribution may give a misleading picture of the surface current pattern. The 23.0 sigma-t isopleth slopes from 20 m. at station 1 toward the surface at station 10, whereas the 23.2 sigma-t isopleth and all those below its depth slope down. Thus, the surface density indicates a southerly component of flow when in reality there exists a strong northerly component.

East of station 22, the varying slopes of the sigma-t isopleths make estimation of the surface current speed and direction difficult without actual dynamic computations. In Alenuihaha Channel (stations 22 to 21) the absence of a pattern associated with well-developed currents is to be expected, since a strong flow normal to the channel direction is not likely.

The depth variations of the 27.0 sigma-t isopleth west of station 22 shows that the distribution of mass associated with the counterclockwise vortex extends to depths greater than 600 m. It also indicates the possibility that currents at that depth are not negligible. But since the direction of slope of the isopleth is the same as those above, the error

s expected to be in magnitude of the surface currents only and not in heir direction.

The salinity distribution is also shown in figure 6 by means of dashed lines (isohalines). A salinity maximum is generally to be found at approximately 100 m. and a minimum at approximately 400 m. The salinity maximum east of station 22 is greater than 35.2 °/oo and west of station 14 less than 35.2 °/oo. In the vicinity of the counterclockwise vortex this salinity structure has broken down with a disappearance of the maximum, which now occurs as a pocket at the surface.

A better over-all picture of the circulation can be obtained from the bathymetric charts of sigma-t surfaces. Figure 7 shows a series of charts for the depths of the 26.5, 26.0, 25.5, 25.0, 24.5, and 24.0 sigma-t surfaces which will convey to some degree the three-dimensional changes in the distribution of mass associated with the circulation. The dashed lines indicate the salinity distribution on the sigma-t surfaces. However, due to the complexity of the circulation and to lack of detail and precision, the usefulness of salinity as a tracer is considerably impaired, so the flow pattern will be deduced from the isobaths.

According to the 26.5 and 26.0 sigma-t surfaces, the direction of flow north of the island chain is from east to west and the deflecting effect of the islands of Hawaii and the group from Maui to Oahu is apparent. The 25.5 and 25.0 sigma-t surfaces indicate a general change of direction to the northeast in the same region. Finally the 24.5 and 24.0 sigma-t surfaces show a southeasterly drift on the windward side except north of Kauai and Kauai Channel, where the flow is from the north.

South of the island chain the flow on the 26.5 sigma-t surface is generally toward the northwest. The position of the counterclockwise vortex is clearly indicated by the 380-m. isobath. The other surfaces show that the vortex features become increasingly dominant toward the surface. In the survey region south of Kauai the northerly component of flow prevails up to the 24.0 sigma-t surface.

In figure 7 the layers which are identified by constant sigma-t values can be considered as independent current systems which, when added together, produce the net surface current. This, essentially, is done in dynamic calculations, using isobaric rather than sigma-t reference surfaces.

The three-dimensional water body of the survey region, extending down to 600 m., can be separated into the surface layer and two intermediate layers. The upper intermediate layer is centered about the salinity maximum, corresponding approximately with the 24.5 sigma-t surface (see fig. 22 for typical temperature-salinity diagrams). The lower layer is centered about the salinity minimum, corresponding approximately with the 26.5 sigma-t surface. The distribution of mass in each is associated with a current pattern and these patterns, when added vectorially, give the net surface circulation. Thus figures 8 and 9, the geopotential topographies at 300 m. relative to the 600-m. level and the geopotential topography at the surface relative to the 300-m. level, illustrate the relative flow pattern of the lower intermediate layer and the upper intermediate layer (including the surface layer), respectively. These, when added, give the surface circulation relative to the 600-m. level (fig. 5).

Bathythermograph Data

Figure 10 represents the vertical bathythermograph temperature distribution oriented in sections from north to south along the lines of stations. At this stage of analysis little additional information can be obtained from these figures, and they are included as a record only. The counterclockwise vortex is clearly indicated by the rising isotherms between stations 12 and 15.

Summary of Cruise

The survey data obtained on cruise 17 of the Hugh M. Smith represent typical summer conditions with normal trade wind weather prevailing. The counterclockwise vortex west of Hawaii was found on previous cruises, which have been discussed by McGary (1955). Two circulation systems were emphasized, the lower intermediate which is associated with the salinity minimum and the upper intermediate which is associated with the salinity maximum. The former consisted of westerly-setting currents north of the island chain which showed the effect of the island barrier. The latter indicated southerly-setting currents impinging on the island chain which were deflected to the southeast by the island group from Oahu to Maui. On the leeward side the upper intermediate circulation was dominated by the counterclockwise vortex. The results of these two systems, together with the surface distribution of mass, is a rather complicated net surface pattern as shown by the geopotential topography (fig. 5).

HUGH M. SMITH CRUISE 20

Summary Cruise Report

Cruise 20 of the Hugh M. Smith extended from February 25, 1953, to April 4, 1953. The area covered was essentially the same as that of previous survey cruises in the offshore waters of the Hawaiian Islands, except for the extension of the western limit to 161°30'W. and the southern limit to 17°20'S. In addition there were two exploratory lines of stations up to 29°N. along 155°W. and 158°W.

Figure 11 shows the position of the 69 hydrographic stations where water samples were collected to a depth of 1,000 m. Oblique zooplankton tows were made to a depth of 200 m. on each station except station 34, where a surface tow was made. Other observations were as follows: bathythermograph lowerings on each station and one between stations; four daily synoptic weather observations, which were passed on to the U. S. Weather Bureau; and GEK observations at each bathythermograph position. These latter were made with unfloated electrodes except on 33 occasions where duplicate GEK runs were made with floated electrodes.

The hydrographic survey part of the cruise began on March 9, 1953. Station 12 was occupied March 15 so that the region south of 24°N., the main survey region, was covered in 19 days.

Meteorological Conditions

No greatly varying weather conditions were encountered throughout the cruise. North of latitude 24°N. the air temperature decreased from 71°F. to 66.5°F. at stations 6 and 7. The average temperature over the whole of the main cruise area was 73°F. Within this area the average air temperature encountered north of the island chain was 72°F., with extremes of 71°F. and 75°F., and to the south it was 74°F. with extremes of 73°F. and 77°F.

Winds were predominantly from 080°T. and ranged from 40° to 130°T. On only ten stations did they have a southerly component. Wind speeds were predominantly within a range of 15 to 22 knots. On only six stations was it greater than 22 knots, with a maximum of 30 knots. Calmer weather (winds less than 15 knots) prevailed during the latter part of the cruise, between stations 52 and 61.

Light rain was encountered on five stations which were scattered throughout the cruise.

Surface Hydrography

The average surface temperature, salinity, and density (sigma-t) in the quadrants of the main survey region are listed in table 2, together with the extremes encountered. The distribution of these variables is discussed below.

Table 2.--Average surface temperatures, salinities, and densities in the quadrants of the survey region, H. M. Smith cruise 20

	Overall average	Northeast of island chain				Southwest of island chain			
		East	West	Over-all	Extremes	East	West	Over-all	Extremes
Temp. (°F.)	74.3	73.5	73.5	73.5	74.3 71.8	74.8	74.9	74.9	76.3 73.4
Salinity (°/oo)	35.00	35.06	35.18	35.11	35.34 34.45	34.75	35.08	34.91	35.33 34.42
Density (σ_t)	23.76	23.93	24.05	23.98	24.35 23.34	23.49	23.74	23.61	24.15 23.27

Temperature distribution

The surface bucket temperatures obtained at each bathythermograph position are contoured on figure 12 at 0.5°F. intervals. The minimum temperature of 71.8°F. south of 24°N. was measured at station 12 and the maximum of 76.3°F. at station 56. Average temperatures showed no significant change from east to west on either side of the island chain.

There were no outstanding features, such as centers of cold or warm water, in the surface temperature distribution. A tongue of warm water extended from the vicinity of stations 59 and 60 northeastward, branching toward Molokai and Hawaii. Two other tongues of relatively warm water extended northward north of Alenuihaha Channel toward station 13 and north of Molokai toward station 24.

In the exploratory section north of 24°N. the surface temperature assumed a more regularly decreasing pattern toward the north. South of 26°N. temperatures tended to increase toward the west, whereas north of this latitude they decreased toward the west.

Salinity distribution

Figure 13 shows the distribution of surface salinity contoured at 0.1 °/oo intervals. As in the case of the surface temperature distribution, there were no outstanding features. Relatively large salinity gradients were encountered east of Hawaii and between 159°W. and 160°W. along the southwest edge of the survey region. A tongue of high salinity water extended south toward and through Kauai Channel until south of Kauai it turned west.

Table 2 shows that the average salinity increased from east to west on each side of the island chain, with extremes of approximately 34.4 °/oo and 35.3 °/oo. Considering the whole cruise area, the salinity increased on the average from south to north, reaching a maximum at approximately 26°N., and then decreased towards 29°N. South of 26°N. the salinity increased from east to west whereas north of this latitude it decreased.

Density distribution

Figure 14 shows the surface density (sigma-t) distribution with contour intervals of 0.1. Both north and south of the islands the density, on the average, increases toward the west, and when figures 13 and 14 are compared, other similarities between the isopleths of salinity and sigma-t become apparent. Some of these are the relatively large gradients east of Hawaii, between 159°W. and 160°W. at the southern edge of the survey region, and high and low salinities south of Kauai and in the vicinity of station 49 which correspond with pockets of high and low sigma-t values, respectively. Thus, south of the island chain the salinity materially influences the surface density distribution, becoming less important on the windward side until north of 24°N. the temperature plays a dominant role.

It was noted above that at 26°N. the salinity and temperature show changes in trend. These are also reflected in the surface density distribution (fig. 14), suggesting that 26°N. may be the southern boundary of a region generally referred to as the subtropical convergence. (See p. 15, Subsurface Circulation.)

Surface circulation

Figure 15 shows the surface circulation represented by the dynamic topography relative to 1,000 m. The survey region is dominated by a number of vortices, some cyclonic, others anticyclonic (counterclockwise, clockwise), centered in the vicinity of stations 49, 39, 1, and 23. The

latter is a large circulatory system which extends from approximately 21°N. to 27°N.

Regions of high current velocities (of the order of 1 to 2 knots) are found in the vicinity of stations 44, 42, 50, 58, west of station 12, and elsewhere. Most of these are on the periphery of the vortices mentioned above.

Figure 15 also shows that the area north of 27°N. is one of stagnation (no currents) except for a northeasterly drift in its northwest section.

Geomagnetic Electrokinetograph (GEK) observations

The GEK (von Arx 1950) observations are plotted on figure 16 in which the arrows indicate the direction of flow and numbers the speed in cm./sec.

On 33 GEK stations duplicate determinations were made with floated (dotted arrows) and unfloated electrodes in order to determine the validity of the "droop" correction (McGary 1955:8). Figure 16 shows that in many cases there was good agreement between the two methods. For a number of observations, however, the currents obtained by the two methods were 90° or more apart, particularly when the GEK indicated low current speeds.

The GEK data have been presented only as a record, and no detailed analysis in relation with the geostrophic[5/] currents has been attempted. However, a superficial comparison between the two methods of obtaining surface currents shows some resemblance, particularly in regions of high current speed. North of 26°N., in the region of weak currents, there is little agreement between the two methods. The region south of 24°N. is one of much vortex activity where it is reasonable to expect vortices both of smaller dimensions and shorter life. Here the GEK which measures essentially instantaneous currents, would be expected to deviate from the geostrophic flow.

Surface temperature, salinity, and density and the surface circulation

It would be desirable to be able to interpret the flow pattern from the distribution of the surface salinity, temperature, and density. In the lee of the island chain some confirmation of the flow pattern is derived

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[5/] Geostrophic currents are those obtained from the geopotential topography.

from these variables. For example, one branch of the forking tongue of warm water is associated with the high velocity current in the vicinity of station 50, and the other with the current at station 42. The latter current continues past the southern tip of Hawaii and corresponds to the large salinity and density gradient in that region. The clockwise vortex centered in the vicinity of station 49 is again apparent from both the salinity and density distribution, as is also the southeasterly setting current near station 58. In Kauai Channel the tongue of high-salinity water is compatible with the dynamic topography, which shows a strong southwesterly setting current coming from the vicinity of the high-salinity source area northwest of the main survey region.

North of the island chain the surface variables are of little help in deducing the flow pattern and, as before, it is expected that the subsurface distribution of variables will help to clarify the picture.

Subsurface Circulation

As in the case of cruise 17, investigation of the subsurface circulation involved the two intermediate systems. The depth of the 24.5 sigma-t surface associated with the salinity maximum and the depth of the 26.5 sigma-t surface associated with the salinity minimum are shown in figures 17 and 18. They indicate that the vortices revealed by the surface dynamic topography do not always extend through the two intermediate flow systems. For example, the vortex near station 39, southwest of Oahu, is clearly apparent on figure 17 but not on figure 18, whereas that at station 49 is apparent on both sigma-t surfaces. North of the island chain the vortex at station 23 is apparent on figure 17 only, and that at station 1 is well pronounced on the 26.5 sigma-t surface only. To illustrate that the complex surface structure extends to great depths, figure 19, showing the depth of the 27.2 sigma-t surface, has been included.

It is interesting to note in figure 17 the rise of the 24.5 sigma-t surface northward until at approximately 26°N. it reaches the sea surface. On the basis of isentropic theory this would be the latitude where the maximum salinity water originates (Sverdrup et al. 1942:141-146).

In figure 20, showing the surface dynamic heights relative to the 300-m. level, the four vortices mentioned above are readily distinguishable.

In figure 21, the dynamic heights at 300 m. relative to the 1,000-m. level, the vortex at station 49 appears considerably weaker and that at station 39 is indistinguishable. North of the island chain the vortex at

station 23 has all but disappeared, whereas that at station 1 has retained a strength similar to that which it showed in the upper layer. Thus the two systems added together give a generally intensified surface flow relative to the 1,000-m. level.

So far the complex current pattern has given no information about any net circulation through the survey region. To gain an understanding of this the dynamic heights of figures 15, 20, and 21 were averaged in each of the four sections of the survey region and north of 24°N. in the exploratory region. These averages are shown in table 3 below.

Table 3.--Average dynamic heights in the quadrants of the survey region

	North of main survey region	Windward side		Leeward side	
		West	East	West	East
300 m. re. 1,000 m.	.96	.84	.81	.82	.81
Surface re. 300 m.	.84	.94	.93	.96	1.00
Surface re. 1,000 m.	1.75	1.78	1.74	1.79	1.81

This shows that there is a westerly drift of the lower intermediate water mass in the northern portion of the cruise area. In the main survey region there appears to be a slight southwesterly drift. The surface circulation relative to the 300-m. level shows a drift, slightly stronger than the intermediate, setting southeast. These two combine to give a net southeasterly surface drift relative to 1,000 m. along the island chain and little net flow in the northern section of the survey region.

Further interesting information can be obtained from an analysis of the salinity minimum. This was suggested by the characteristic shape of temperature salinity diagrams, some of which are shown in figure 22. At station 5, for example, the temperature, salinity, depth, and sigma-t of the salinity minimum are 5.3°C., 33.97 °/oo, 620 m., and 26.8 respectively. At station 62 these same variables are 11.3°C., 34.18 °/oo, 270 m and 26.1. These are the extreme values, the former representing a type of water found in the northern section of the cruise area, and the latter a type found in latitudes south of the island of Hawaii. Values between these extremes are found throughout the remainder of the survey area. Some of the curves also indicate a double minimum, such as at stations 61 and 64

fig. 22). This suggests that the islands are located in a region bounded by intermediate water masses from a different source and supports the schematic figure 202 in Sverdrup et al. (1942:717).

Also interesting to note is the shape of the T-S curve at the salinity minimum. There are a number of stations such as station 29 (fig. 22), where the salinity remains essentially constant between the extremes of sigma-t mentioned above, which might suggest mixing of the two types of water.

To illustrate these observations, figure 23 has been prepared showing schematically two types of water at the salinity minimum which were separated arbitrarily at 26.5 sigma-t. Cross-hatched zones include the stations of constant salinity throughout the sigma-t range. The lack of a more definite flow pattern on this diagram is in agreement with the averaged dynamic heights for the lower intermediate flow, which show only a weak net circulation.

Bathythermograph Data

Bathythermograph data are again included as a record only in vertical sections on figure 24.

Summary of Cruise

Cruise 20 of the Hugh M. Smith took place during oceanic winter conditions with trade wind weather.

The hydrographic data showed considerable complexity extending down through the salinity minimum layer with four major vortices which obscured any mean flow pattern. Average dynamic heights at 300 m. relative to 1,000 m. indicated a southwesterly drift through the main survey region. Those at the surface relative to the 300-m. level revealed a slightly stronger easterly drift. These two systems combined to give a net easterly flow along the island chain and no net current in the northern section of the survey region.

The large number of vortices show that the survey region is one of dissipation of energy with little or no net transport. The absence of any "streams" impinging on the island chain either at surface or intermediate depths suggests the existence of mechanisms for vortex generation other than those associated with current shears.

HUGH M. SMITH CRUISE 21

Summary Cruise Report

The cruise began August 4 and was completed August 25, 1953, with the occupation of 69 stations whose location is shown in figure 25. All of these were hydrographic stations with sampling depths to 500 m. except 23 and 33, which were trawl stations. Three duplicate sets of four stations were occupied in Kaiwi Channel, but only stations 28, 29, 30, and 31 of these are used in the analysis in order to provide better continuity in time. Station 5 was occupied on August 6 and station 65 on August 24, so that the survey region was covered in 18 days.

Other observations included 200-m. oblique plankton tows and bathythermograph and GEK observations at each station and at 20-mile intervals. Four daily synoptic weather observations were made and passed on to the U. S. Weather Bureau.

Meteorological Conditions

Typical trade wind weather was encountered during the cruise. The overall average air temperature was 77.3°F. On the windward side the average was 76.6°F. and on the leeward side 77.8°F. The lowest temperature of 75.1°F. was encountered at station 9 and the highest, 81°F., at station 32 in the immediate lee of Lanai Island. Of the winds which were measured on the hydrographic stations, 65 percent were from 070° to 090°T.; 90 percent of the winds came from 050° to 120°T. The winds had an extreme southerly component on only two occasions, namely on stations 37 and 38 when the direction was 220°T. and 170°T., respectively. The measured wind speeds were 46 percent between 17 and 21 knots, 30 percent between 11 and 16 knots, 12 percent greater than 21 knots, and 12 percent less than 11 knots.

The weather was generally fair except on stations 5 to 8, 37, and 46, when showers were encountered.

Surface Hydrography

The distribution of the surface temperature, salinity, and density are again discussed separately. Table 4 shows these variables averaged over the quadrants of the survey region together with the extreme values encountered.

Table 4.--Average surface temperatures, salinities, and densities in the quadrants of the survey region, H. M. Smith cruise 21

	Overall average	Northeast of island chain				Southwest of island chain			
		East	West	Over-all	Ex-tremes	East	West	Over-all	Ex-tremes
emp. °F.)	78.0	76.9	77.2	77.0	77.7 76.3	78.3	79.0	78.6	79.5 76.6
alinity °/oo)	34.99	35.06	34.99	35.02	35.27 34.79	34.92	35.02	34.97	35.11 34.82
ensity (σ_t)	23.18	23.43	23.32	23.37	23.52 23.21	23.10	23.02	23.07	23.47 22.92

Temperature distribution

The surface bucket temperatures obtained at each bathythermograph position are contoured on figure 26 at 0.5°F. intervals. As during cruise 17 (September), the greatest deviations occurred on the leeward side, where maximum temperatures of about 79.5°F. were found west of the island of Hawaii, in the vicinity of station 37, along the southern border of the survey region between stations 59 and 65, and between stations 40 and 41, south of the island of Oahu. The coldest water, 76.6°F., on the leeward side of the island chain was found in the southeast section of the survey region and in a pocket at station 51. On the windward side the temperatures were more uniform, as was also the case during cruise 17, and ranged from 76.3°F. in the east to 77.7°F. in the west.

The increasing average temperatures from east to west on both sides of the island chain suggest that there exists a net surface flow with a westerly component, considering that the survey region is located within latitudes of net gain of heat energy. On the leeward side, the higher temperatures and the greater deviations suggest a slower surface transport to the west. Noteworthy is the horizontal temperature gradient along the island chain. This and the other features point to the assumption that water with a westerly component of flow is impinging on the island chain, which provides an effective barrier.

Salinity distribution

Figure 27 shows the surface salinity distribution contoured at 0.1 °/oo intervals. On the windward side the maximum salinity of 35.27 °/oo was found at station 8 and at stations 10 and 15, in a tongue extending from north to south toward the island of Hawaii, where the salinity was 35.26 °/oo. The lowest salinity, 34.79 °/oo, was found at station 5. On the leeward side the maximum salinity of 35.11 °/oo was found at station 63 and the minimum of 34.82 °/oo at station 58, both along the southern boundary of the survey region. Also of interest is the pocket of higher salinity at station 51. In general, the average salinity decreased westward north of the island chain whereas it increased in that direction south of the islands.

An isolated pocket of low salinity water (34.55 °/oo), lower than the minima mentioned above, was found at station 26 in Kauai Channel. Although this seems unreasonably low, no reason such as faulty sampling or chemical analysis can be found to discard the observations.

Density distribution

The surface density distribution in units of sigma-t was contoured at 0.1 intervals on figure 28. It shows that on the windward side the extreme sigma-t values were found at station 5, where the minimum was 23.21, and at station 10, where the maximum was 23.59. On the leeward side the highest sigma-t value, 23.47, was found at station 51, and the lowest, 22.92, at station 35 west of Hawaii and station 40 south of Oahu.

Figures 26, 27, and 28 indicate the relative influence of temperature and salinity in the density distribution. For example, the surface temperature and density show the feature of relatively large horizontal gradients along the island chain, which is absent in the salinity distribution. One can also note the pockets of warm water south of Oahu and west of Hawaii corresponding with lower densities in the same regions.

On the windward side of the island chain one can detect the influence of salinity in the surface distribution of density. For example, north of the island of Hawaii the tongue of saline water extending from north to south is reflected in a tongue of denser water in spite of higher surface temperatures. This indicates that the salinity has become the dominant variable in the density distribution. At station 51, on the leeward side, it can be seen how both low temperature and high salinity contribute to the high density, which, as before, is associated with a counterclockwise vortex.

In general, the average surface density decreases from east to west and south to north. Thus, remembering that in the northern hemisphere the light water is to the right of an observer facing in the direction of flow, the density distribution suggests that the contribution to the net surface flow is a relative current setting southeast.

Surface circulation

For cruise 21 dynamic calculations are limited to the upper 500 m. These depths (500 m.) are approximately the depths of the salinity minimum during this cruise. A considerable part of the contribution toward the surface flow due to the intermediate distribution of mass is therefore not shown. This, however, is not expected to change materially the presentation of the main features of the circulation.

The dynamic topography at the surface relative to the 500-m. level (fig. 29) shows that the survey region is again one with a complex flow pattern. There appear in the lee of the islands three vortices. Two of these, centered in the vicinity of stations 47 and 51, show a counterclockwise rotation, and the larger, third vortex, centered in the vicinity of 20°N., 158°W., shows a clockwise rotation. Highest current speeds in the order of 1 to 2 knots occur again on the periphery of the vortices. In the northern section of the survey region an easterly current turns south between 157° and 158°W. and then flows west just north of the island chain. North of Hawaii a southwesterly current enters the survey region and is deflected to the southeast off the island's coast. The circulation about the island of Hawaii is clockwise.

Geomagnetic Electrokinetograph (GEK) observations

The GEK surface current vectors are plotted in figure 30. The arrows indicate the direction of flow and numbers the speed in cm./sec. All observations were made with unfloated electrodes and subsequently corrected for the "droop" effect.

As before, no detailed analysis is made, but when figures 29 and 30 are compared, agreement between GEK and geostrophic current direction and relative speed is apparent. High GEK speeds occur between the major vortices of figure 29, and the directions there as well as in regions of lower current speed are in good agreement. Interesting to note is the agreement between the GEK currents and the geostrophic current in Kauai Channel. Both figures 29 and 30 show northwesterly flow in the eastern part and southwesterly flow in the western part of the channel.

The agreement of the two methods is general only, and instances such as at stations 19 and 22, where the directions are 90° to 180° out of phase, can be found. The GEK current speeds also appear higher by as much as a factor of 2, as between stations 57 and 58.

Surface temperature, salinity, density and the surface circulation

As before, the surface distribution of variables is of little help in deducing the flow pattern. Only the counterclockwise vortex at station 51 is apparent in figures 26 and 27 from the low temperature and high salinity, respectively. The sigma-t distribution together with the high temperatures west of Hawaii suggest a clockwise circulation about the island. North of Hawaii, figures 27 and 29 show that the tongue of high salinity water is carried into the survey region by the southeasterly setting current.

The lack of agreement between the flow expected from the surface density distribution and that obtained from the dynamic height anomalies again points to the importance of the subsurface distribution of mass.

Subsurface Circulation

The bathymetric chart of the 24.5 sigma-t surface approximately associated with the salinity maximum is shown in figure 31. The isobaths clearly indicate the three vortices in the vicinity of stations 45, 49, and 51. The counterclockwise vortices are identifiable by "doming" and the clockwise vortex by a depression in the sigma-t surface. The resemblance between the isobaths of the 24.5 sigma-t surface and the dynamic height contours at the surface relative to 250 m. (fig. 32), both north and south of the island chain, should be noted. This means that the bathymetric chart of the 24.5 sigma-t surface essentially indicates the relative flow of the intermediate layer, associated with the salinity maximum. This also suggests that the distribution of mass on the salinity maximum layer (sigma-t 24.5) is of greater importance than the surface distribution of mass (fig. 28).

The bathymetric chart of the 26.5 sigma-t surface, approximately at the salinity minimum, is presented in figure 33. Evidence of vortex motion southwest of the island chain is still apparent but less distinct. The location of the counterclockwise vortices is indicated by ridges protruding into the survey region from the southwest, and the clockwise vortex is indicated by a trough extending southward from the Oahu and Molokai region.

The contribution to the surface circulation due to the intermediate flow associated with the salinity minimum is illustrated by the dynamic topography at 250 m. relative to the 500-m. level (fig. 34). It can be seen that the vortices in the vicinity of stations 49 and 51 extend to the depths of the salinity minimum. The vortex at station 45 is, however, obscured by a northeasterly setting current, the direction of which is reversed south of Oahu and in Kaiwi Channel to continue as the westerly setting current south of Kauai. Similar isopleth patterns in figures 33 and 34 again show that the isobaths of the 26.5 sigma-t surface at the salinity minimum give a good indication of flow in this layer. Discrepancies can probably be attributed to the fact that the dynamic height at 250 m. relative to the 500-m. level reflects the distribution of mass only in the upper portion of the flow layer associated with the salinity minimum.

The salinity distribution on the 24.5 and the 26.5 sigma-t surfaces is also indicated by dashed lines in figures 31 and 33 and becomes plausible if studied in conjunction with the dynamic topography at the surface relative to the 500 m. and that at 250 m. relative to the 500-m. level. The usefulness of tracing currents by this method, however, is impaired by the complexity of the system.

A comparison of the dynamic heights presented in figures 29, 32, and 34 shows that the major features in the two intermediate systems are quite similar and generally have an additive effect on the net surface circulatory pattern. The spacing of the contour lines southwest of the island chain is closer in figure 32 than in figure 34, which means that the contribution due to the intermediate system associated with the salinity maximum is of primary importance. Northeast of the island chain the contour line spacing is approximately the same in the two figures, indicating that there the two systems contribute equally.

Differences in the contour line patterns of the two systems (figs. 32 and 34) exist north of the islands of Kauai and Oahu and in the vicinity of station 47. The clockwise circulation about the island of Hawaii is also absent in the deeper flow pattern (fig. 34).

The averaged dynamic height anomalies at 250 m. relative to the 500-m. level in each subdivision of the survey area show a net drift toward the island chain from the northeast which is deflected to the northwest. The same computations for the surface flow relative to the 250-m. level also show a net drift toward the island chain from the northeast, which in this case is deflected toward the southeast. The net motion on the leeward side of the island chain appears negligible in each case. These observations are in agreement with the averaged dynamic heights

at the surface relative to 500 m., where the northwesterly current impinging on the island chain is deflected to the northwest and southeast.

Bathythermograph Data

As before, the bathythermograph data have been included as a record only and are presented by vertical sections in figure 35.

Inorganic Phosphate

On Hugh M. Smith cruise 21 good, reproducible inorganic phosphate data, analyzed aboard ship by the method described by Wooster and Rakestraw (1951), were obtained. The surface values were plotted on figure 36 and show little variation. The average phosphate-phosphorus concentration on the windward side of the island chain was approximately 0.2 μg-at/l and on the leeward side 0.3 μg-at/l. A tongue of low-phosphate water (less than 0.2 μg-at/l) reached into the survey region between stations 5 and 9 and extended toward the island of Hawaii. This is in good agreement with the surface currents as shown in figure 29. A tongue with a high phosphate concentration (greater than 0.4 μg-at/l) appears between stations 58 and 60 and extends to station 39, between the counterclockwise and clockwise vortices centered in the vicinity of stations 51 and 49 (fig. 29).

Figure 37 shows the phosphate distribution on the 24.5 sigma-t surface. In general the average concentration is lower on the windward side (0.2 μg-at/l) than on the leeward side (0.3 μg-at/l). Interesting to note is the similarity of the isopleth structure of phosphate-phosphorus and salinity (fig. 31) on the windward side of the island chain. On the leeward side, the outstanding feature is the pocket of low-phosphate water (less than 0.2 μg-at/l) in a region where the average concentration is greater than 0.3 μg-at/l. This pocket is located in the vicinity of station 39, to the northeast of the clockwise vortex (fig. 29), within a tongue of lower phosphate water extending southward through Kaiwi Channel.

The phosphate distribution on the 26.5 sigma-t surface is shown in figure 38, where again the concentration is lower on the windward side (generally less than 2 μg-at/l) than on the leeward side (generally greater than 2 μg-at/l). A tongue of lower phosphate water reaches southward through Kauai Channel toward station 49, and another through Alenuihaha Channel to station 38. Again there are similarities in the isopleth structure of the phosphate and salinity concentration (fig. 33) on the 26.5 sigma-t surface.

Summary of Cruise

Cruise 21 of the Hugh M. Smith took place during summer onditions, with typical trade wind weather prevailing. The systems dentified by the salinity minimum, the salinity maximum, and the sur- ace waters were again investigated separately. It was shown that the urface current pattern southwest of the island chain was primarily nfluenced by the system associated with the salinity maximum (fig. 32, hich in its computation includes the surface distribution of mass). ortheast of the island chain the dynamic computation showed that the ower intermediate system and the upper intermediate system together ith the surface system were of approximately equal importance.

There was little or no net transport of water through the survey egion on the leeward side in either of the intermediate systems. On he windward side water was renewed from the north or northeast and hen deflected both to the northwest and southeast. The northwest de- ection was primarily due to the flow associated with the salinity inimum.

GEK observations showed general agreement with currents btained from dynamic computations. This might be expected when ne considers that the system during the summer becomes less complex nd that therefore the instantaneous GEK observations are in closer greement with average current conditions.

Inorganic phosphate observations showed that the surface concen- ration on the leeward side of the island chain was greater than on the windward side, although the difference was small. This suggests, as vas shown by dynamic computations, that on the windward side there xists a continuous influx of new, low-phosphate water. On the leeward ide, the stationary surface waters may be enriched by vertical mixing r island drainage.

DISCUSSION

The purpose of this report has been the presentation of data vhich were collected on cruises 17, 20, and 21 of the Hugh M. Smith. Two of these occurred during the summer months of August and Septem- er and one during the winter months of February and March.

The data for each cruise were examined separately, first the urface and then the subsurface layers. Important and interesting

features were pointed out, but in general no attempt has been made to interpret or explain them. It is felt that the information gained from each cruise is but a fragment of the oceanographic picture of the Hawaiian Islands region and a more complete understanding must wait until all the available data can be synthesized.

Surface Variables

The surface layer has been given special attention because in it the primary production of the sea takes place. The surface parameters of temperature, salinity, and density can also be used as indices of seasonal and longer period changes in the oceanic environment.

An understanding of the surface temperature is particularly useful because of the easy manner in which it can be measured by thermometer and bathythermograph. Generally temperature is the important independent variable in the density distribution, which in turn is used to obtain the relative current picture. In the Hawaiian Islands region, however, it was shown that salinity is also important in the distribution of surface density.

Table 5 below summarizes for each cruise the averaged surface temperature, salinity, and density (sigma-t) in the four sections of the survey region. On the basis of data from one winter and two summer cruises, one can only hint at the seasonal trends and point to interesting features. By studying the temperature, for example, one finds that the seasonal range is about 4°F., which is less than the extreme range of almost 6°F. encountered during cruise 17. The extreme ranges on the windward and leeward sides of the island chain on cruises 20 and 21 did not indicate any clear seasonal trend. The leeward side of the island chain was dominated during cruise 17 by a large counterclockwise vortex, whereas during cruises 20 and 21 there were a number of smaller vortices in this region. Thus, the temperature range might indicate the type of vortex activity.

Although the average salinities changed from cruise to cruise, no seasonal trend is indicated. Figures of the surface salinity distribution suggest that the changes are not due to island runoff only, but also to varying concentrations outside the survey region.

It is interesting to note that the salinity range in each cruise shows a seasonal trend. On cruise 17 (summer) the extreme range was about $0.3^{\circ}/oo$, on cruise 20 (winter) $0.9^{\circ}/oo$, and on cruise 21 (summer) $0.5^{\circ}/oo$. Another interesting feature is the slightly

Table 5.--Average surface temperatures, salinities, and densities for H. M. Smith cruises 17, 20, and 21

	Overall survey region	Northeast of island chain				Southwest of island chain			
		East	West	Over-all	Ex-tremes	East	West	Over-all	Ex-tremes
).)									
ise 17					79.0				80.5
ept.)	78.0	77.6	77.5	77.6	77.0	78.0	79.2	78.6	74.8
ise 20					74.3				76.3
larch)	74.3	73.5	73.5	73.5	71.8	74.8	74.9	74.9	73.4
ise 21					77.7				79.5
ugust)	78.0	76.9	77.2	77.0	76.3	78.3	79.0	78.6	76.6
ity o)									
ise 17					35.33				35.28
Sept.)	35.12	35.18	35.15	35.15	35.05	35.08	35.05	35.06	34.95
ise 20					35.34				35.33
March)	35.00	35.06	35.18	35.11	34.45	34.75	35.08	34.91	34.42
ise 21					35.27				35.11
August)	34.99	35.06	34.99	35.02	34.79	34.92	35.02	34.97	34.82
ity)									
ise 17					23.58				23.67
Sept.)	23.25	23.37	23.34	23.36	23.04	23.23	23.05	23.14	22.80
ise 20					24.35				24.15
March)	23.76	23.93	24.05	23.98	23.34	23.49	23.74	23.61	23.27
ise 21					23.52				23.47
August)	23.18	23.43	23.32	23.37	23.21	23.10	23.02	23.07	22.92

increasing trend of salinity from west to east during cruise 17, and a more definite increasing trend from east to west during cruise 20 on both sides of the island chain. During cruise 21 the salinity increased from west to east on the windward side and from east to west on the leeward side of the island chain.

Variations in the average surface sigma-t values show the combined effects of the temperature and salinity variations. The sigma-t values are higher in winter than in summer and for each cruise they are also higher on the windward side of the islands, reflecting the temperature effect. The greater range in extreme values of sigma-t for the winter cruise than for the summer cruises reflects the influence of salinity on the density.

It is interesting to note that the sigma-t values increased from southwest to northeast during the summer cruises and from south to north during the winter cruise. Thus, the relative current due to the surface distribution of mass would drift southeastward in summer and eastward in winter.

Surface Currents

The investigation of surface variables was followed by a study of the surface current pattern, which generally was one of complexity with little net transport through the survey region.

The dynamic topography (fig. 5) of cruise 17 showed that the leeward region was dominated by a large counterclockwise vortex. The currents on the windward side appeared to be very weak, except for one in the region north of Kauai setting southwest at approximately 0.4 knots.

The dynamic topography of cruise 21 (fig. 29). showed two counterclockwise vortices in the lee of the island chain. The position of the counterclockwise vortex of cruise 17 was now occupied by a large clockwise vortex. The current pattern on the windward side of the island chain also appeared more complex than on cruise 17.

The most confusing current pattern was shown by the dynamic topography of cruise 20 (fig. 15), when both sides of the island chain were dominated by vortex motion apparently without a systematic pattern.

Subsurface Circulation

The currents deduced from the surface density (the light water is to the right of an observer facing in the current direction) were not

always in agreement with those obtained from surface dynamic heights. This emphasized the importance of the subsurface distribution of mass. The survey data indicate three major systems within the POFI sampling depths: the system associated with the surface distribution of mass, that associated with the salinity maximum, and that associated with the salinity minimum.

The 24.5 and 26.5 sigma-t surfaces were generally associated with the salinity maximum and the salinity minimum, respectively. Their isobaths would give an indication of the direction of flow at these levels. Conventional isentropic analysis, however, such as plotting the variation of a tracer, like salinity, on surfaces of potential density (sigma-t) was not successful in the Hawaiian Islands region.

The relative importance of the systems associated with the salinity maximum and minimum was further investigated by means of dynamic height anomalies in these layers. The reference levels were the maximum sampling depths (600 m. for cruise 17, 1,000 m. for cruise 20, and 500 m. for cruise 21) and the approximate depth of the inflection point between the salinity maximum and the salinity minimum on the temperature-salinity diagram (fig. 32). Thus for cruise 17 the contribution to the net surface flow due to the system associated with the salinity minimum would be represented by the dynamic height anomalies at 300 m. relative to the 600-m. level. The contribution to the net surface flow due to the upper layer, associated with the salinity maximum and the surface distribution of mass, would be represented by the dynamic height anomalies at the surface relative to 300 m. The latter gives the current directions and magnitudes relative to the currents at 300 m. (The concept of relative motion is familiar to navigators, for because of current motion the actual path of a vessel may be quite different from either the course steered or the current direction.) This presentation shows the relative importance of the distribution of mass associated with two subsurface flow systems, the upper of which would include the effect due to the surface distribution of mass.

The dynamic topographies of the intermediate water masses associated with the salinity minimum of the three cruises were shown in figures 8, 21, and 34. In each case any net flow through the survey region is obscured, except in figure 8 of cruise 17, where the westerly flow is clearly in evidence. Qualitatively, the averaged dynamic heights for cruises 20 and 21 show a southwesterly setting drift passing through the survey region. Differences between the averaged dynamic heights in the quadrants of the survey region for each cruise indicate that the strength of currents during the summer months (cruises 17 and 21) is approximately twice that observed during the winter cruise.

Figures 9, 20, and 32 showed the relative flows of the upper intermediate layer associated with the salinity maximum. In each case the complex pattern obscured any net current trend. Qualitatively, the averaged dynamic heights indicate that during cruise 17 a weak, southwesterly current passed through the survey region with some of the water being deflected toward the northwest and southeast along the island chain. For cruise 20 a southeasterly drift was indicated along the island chain, and for cruise 21 the averaged dynamic heights showed a southerly current impinging on the islands which was deflected toward the southeast. The net current strength during cruises 20 and 21 was approximately twice that of cruise 17, but in cruise 21 the direction changed toward that observed for cruise 17. The indicated seasonal variation in the relative drift direction of the upper intermediate layer was a feature also noted in the surface layer.

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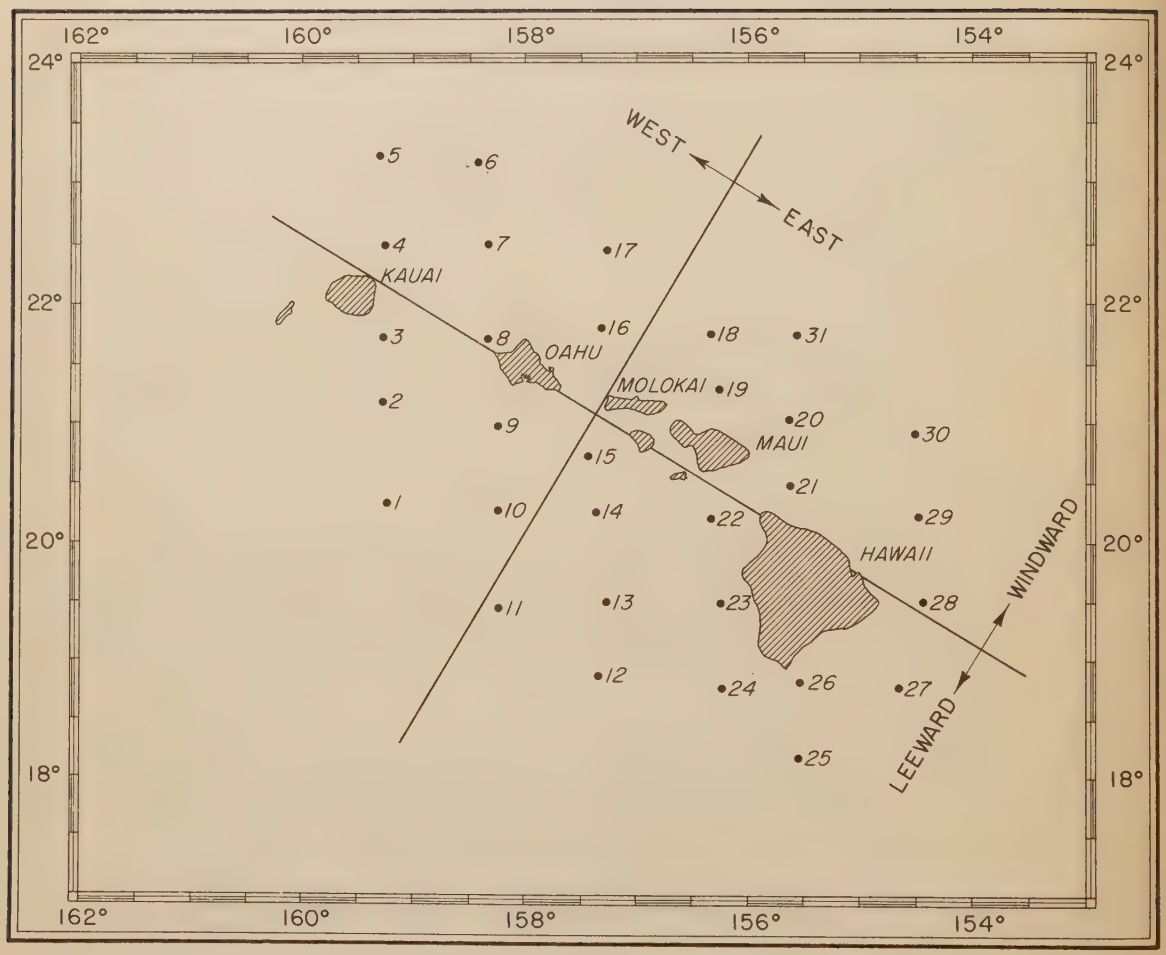

Figure 1. --Station positions, H. M. Smith cruise 17, September 1952. The straight lines indicate the subdivision of the survey region into quadrants.

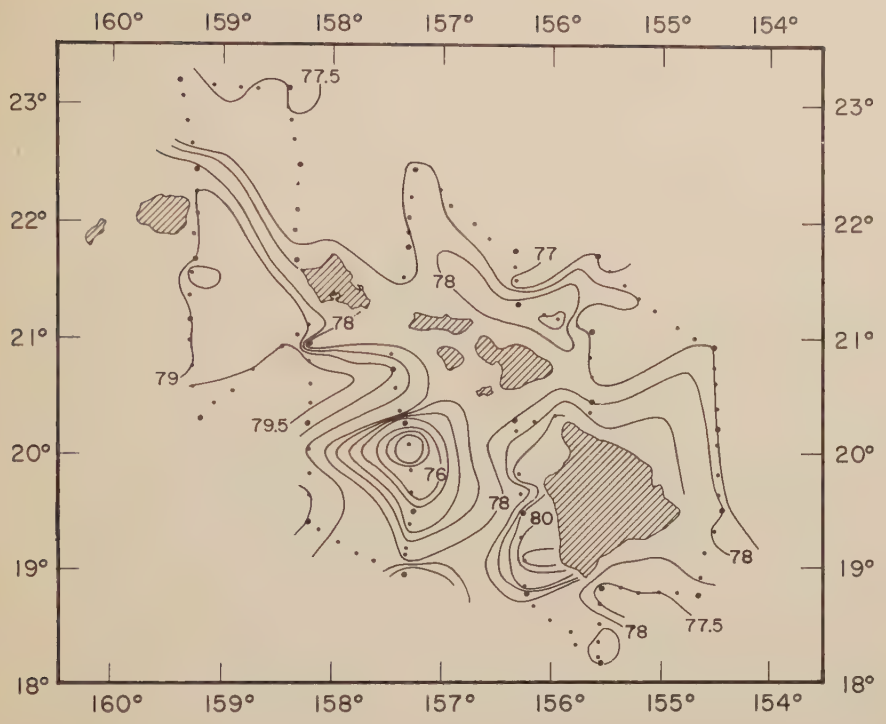

Figure 2.--Surface bucket temperatures in °F., with contour intervals of 0.5°F. H. M. Smith cruise 17, September 1952.

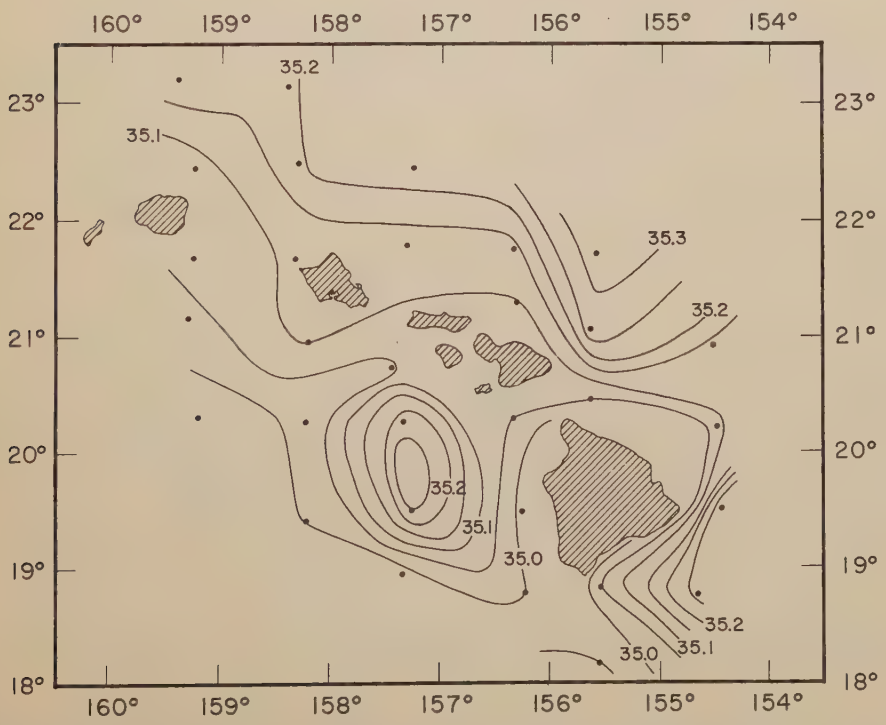

Figure 3.--Surface salinity in °/oo, H. M. Smith cruise 17, September 1952. Contour interval 0.05 °/oo.

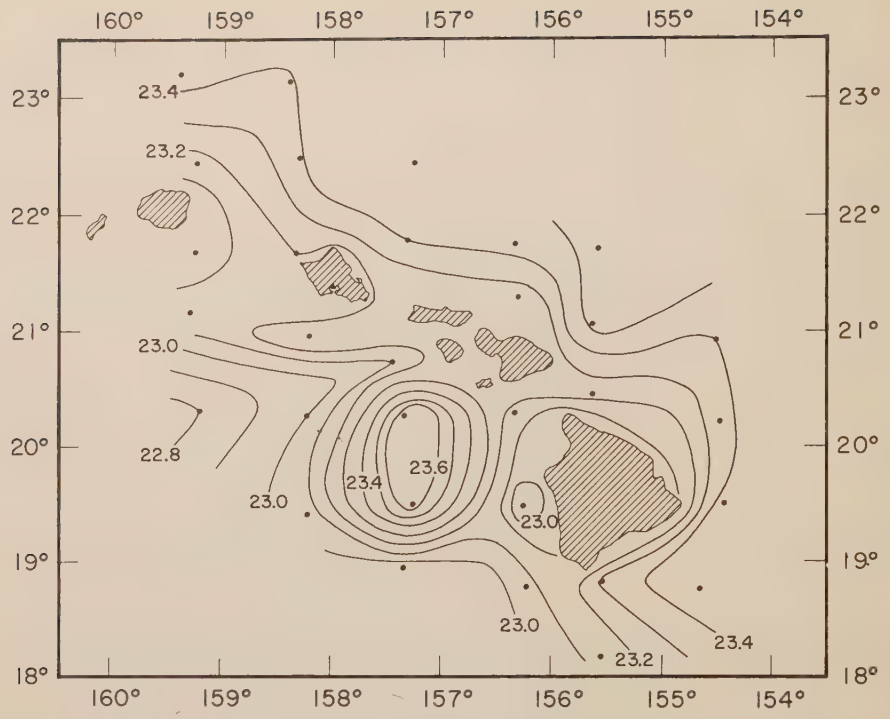

Figure 4.--Surface density (sigma-t), H. M. Smith cruise 17, September 1952. Contour interval 0.1.

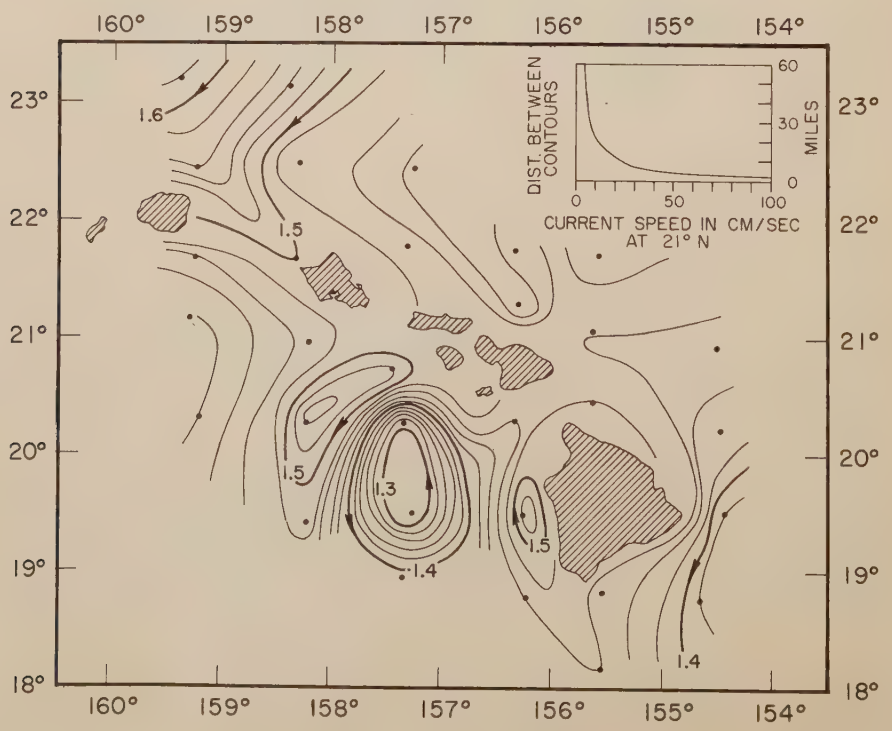

Figure 5.--Dynamic height anomalies (dynamic meters) at the surface relative to 600 m., H. M. Smith cruise 17, September 1952. Contour interval 0.02 dynamic meters.

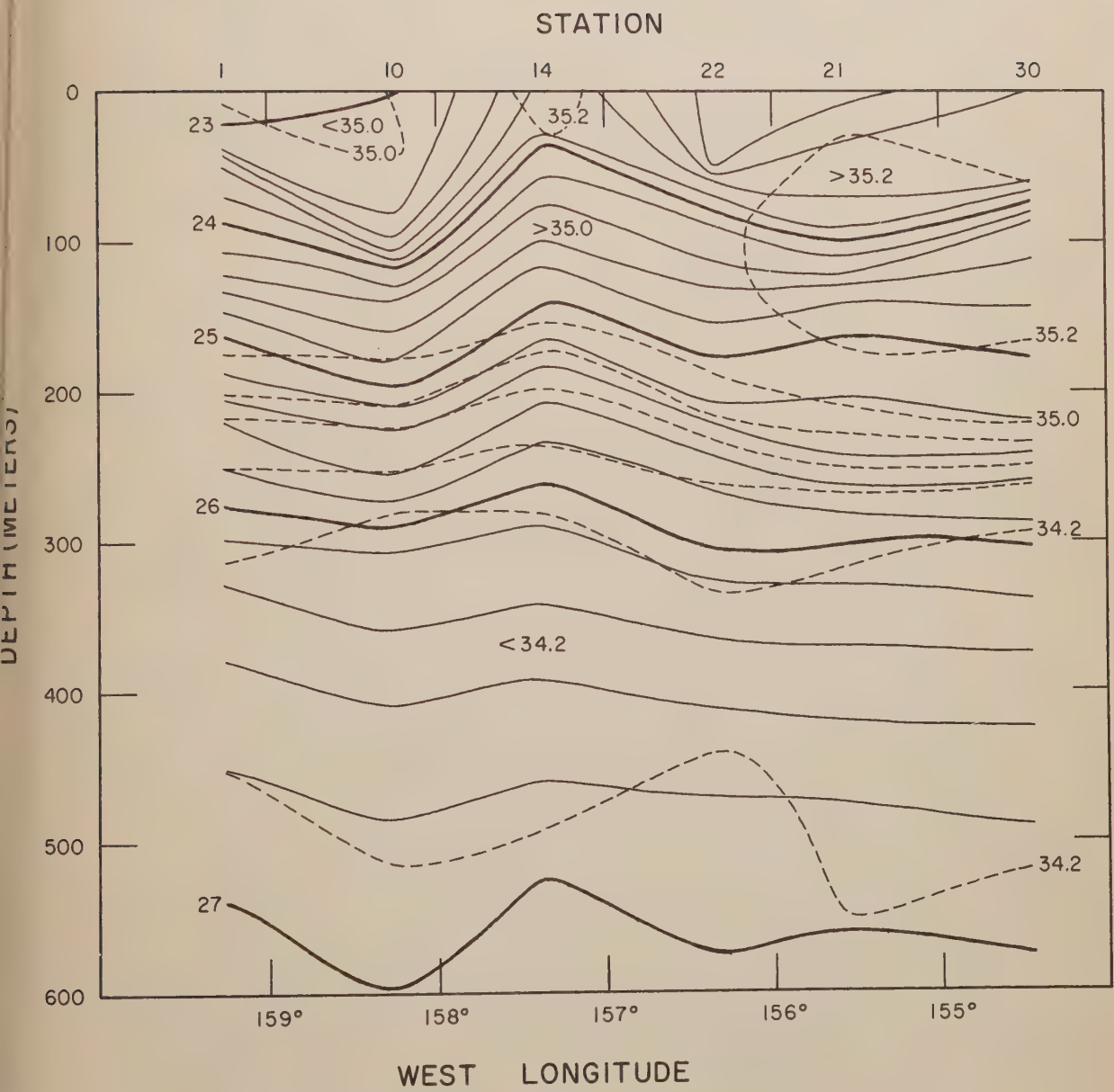

Figure 6.--Density (sigma-t) section (solid lines) and salinity (^{o}/oo) section (dashed lines) through stations 1, 10, 14, 22, 21, and 30, H. M. Smith cruise 17, September 1952. Sigma-t contour interval is 0.2, salinity contour interval 0.2 ^{o}/oo.

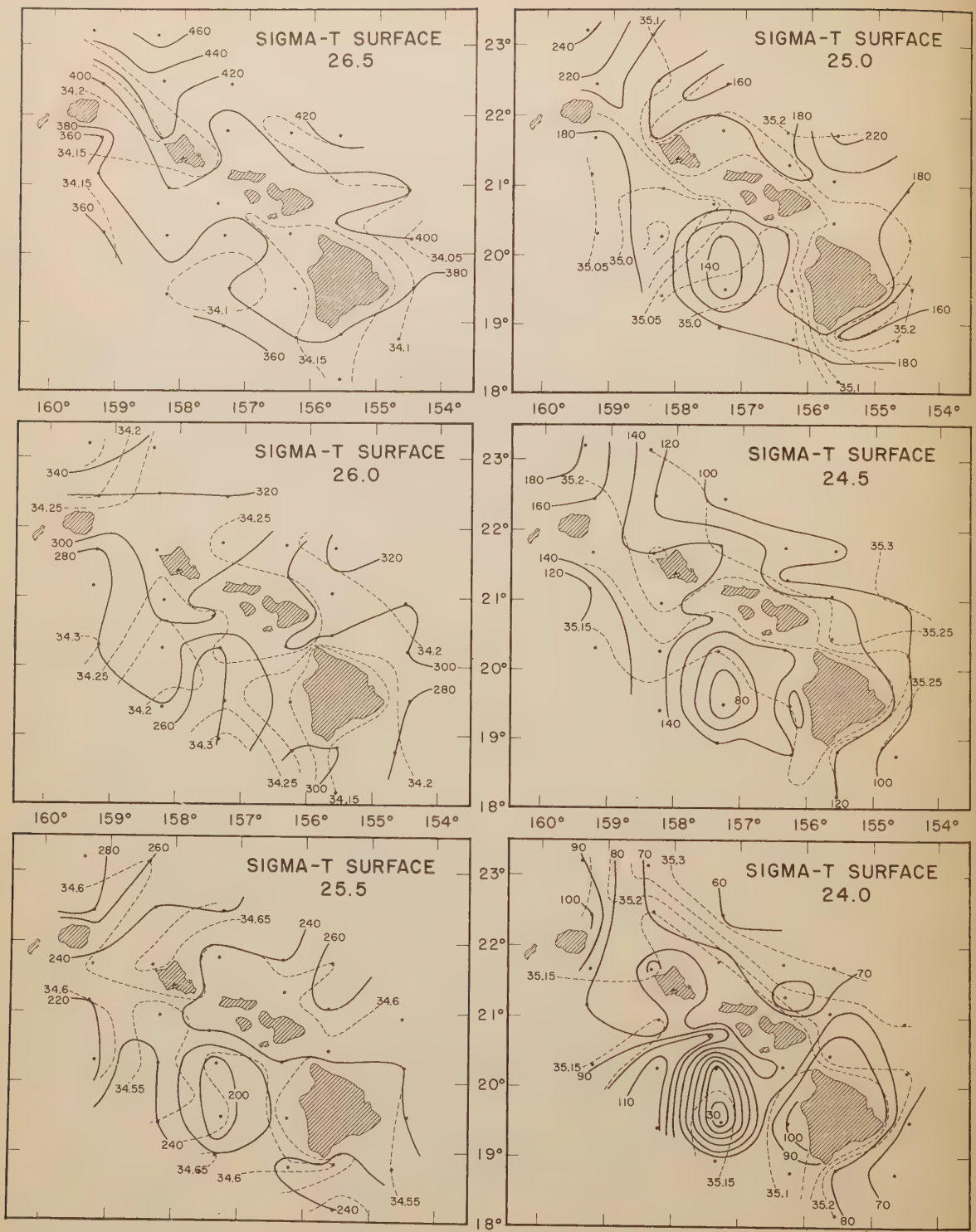

Figure 7.--Bathymetric chart (depth in meters) of the 26.5, 26.0, 25.5, 25.0, 24.5, and 24.0 sigma-t surfaces, H. M. Smith cruise 17, September 1952. Contour interval 20 m. Dashed lines indicate the salinity ($^{o}/oo$) distribution on these surfaces with contour intervals of 0.5 $^{o}/oo$.

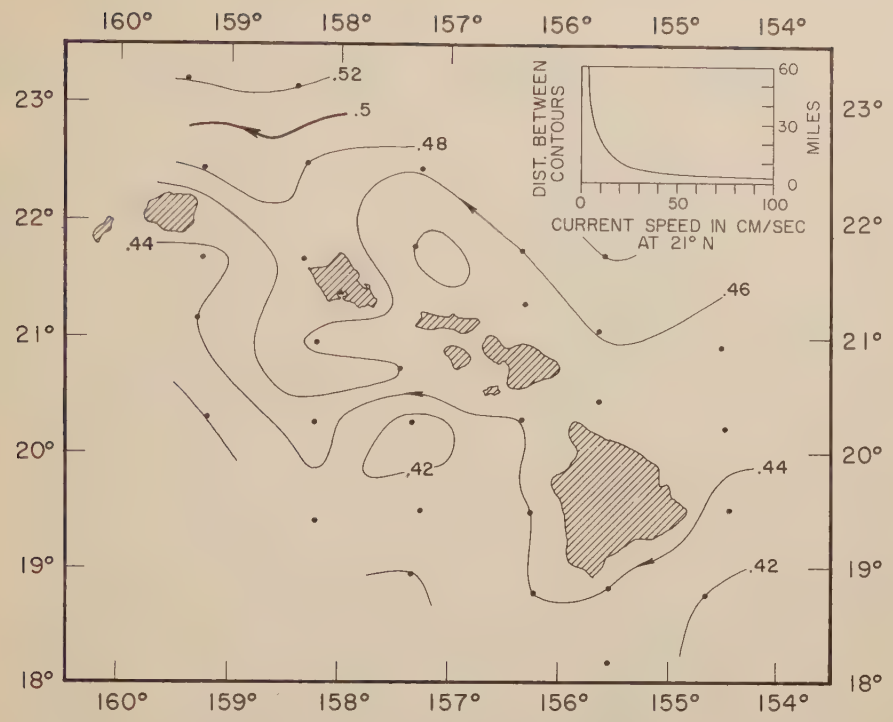

Figure 8.--Dynamic height anomalies (dynamic meters) at 300 m. relative to 600 m., H. M. Smith cruise 17, September 1952. Contour interval 0.02 dynamic meters.

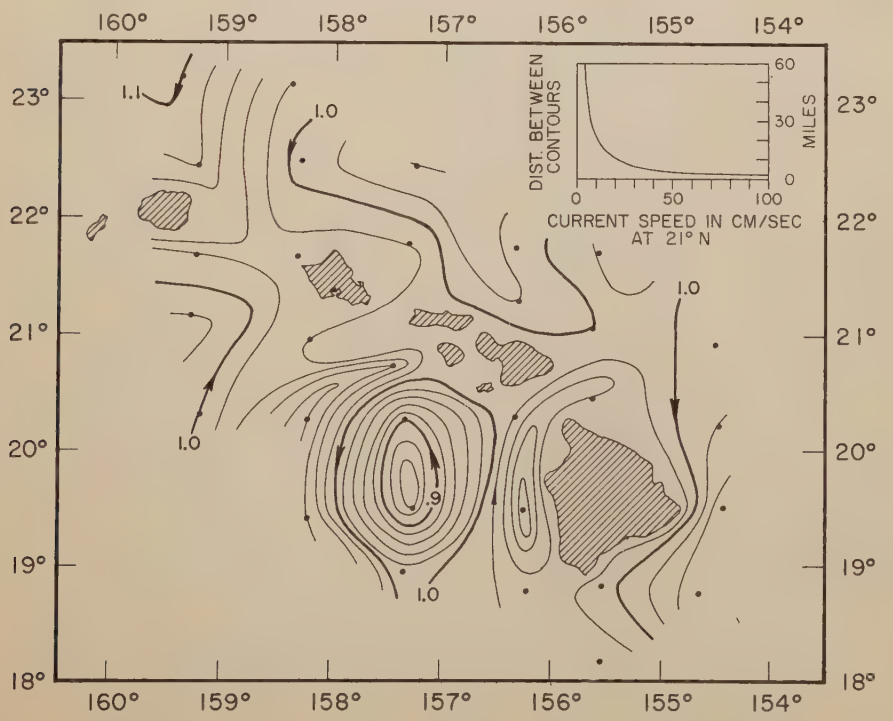

Figure 9.--Dynamic height anomalies (dynamic meters) at the surface relative to 300 m., H. M. Smith cruise 17, September 1952. Contour interval 0.02 dynamic meters.

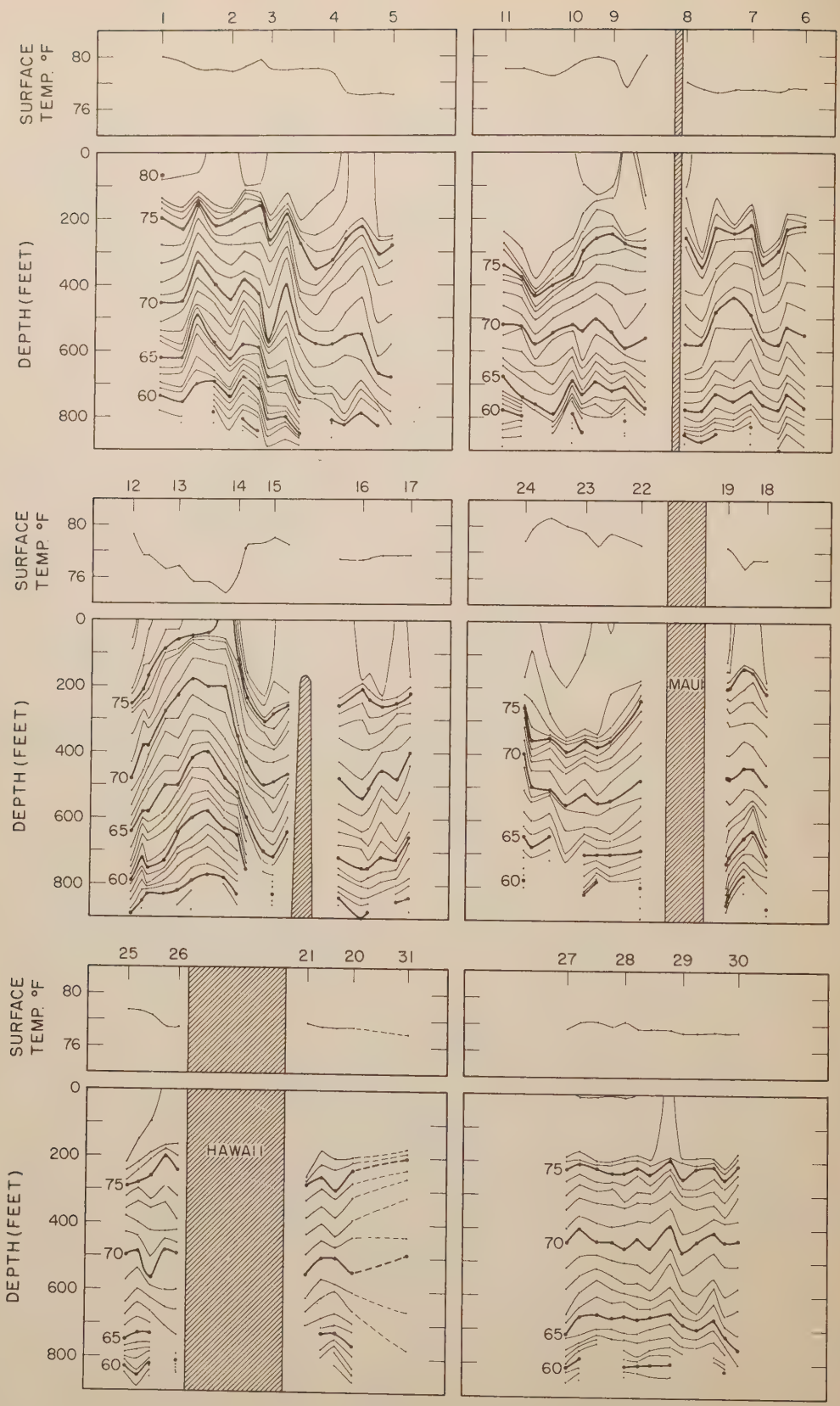

Figure 10.--Vertical bathythermograph temperature (°F.) sections from stations 5 to 1, 6 to 11, 17 to 12, 18 to 24, 31 to 25, and 30 to 27, H. M. Smith cruise 17, September 1952. The upper panels show the surface bucket temperatures in °F.

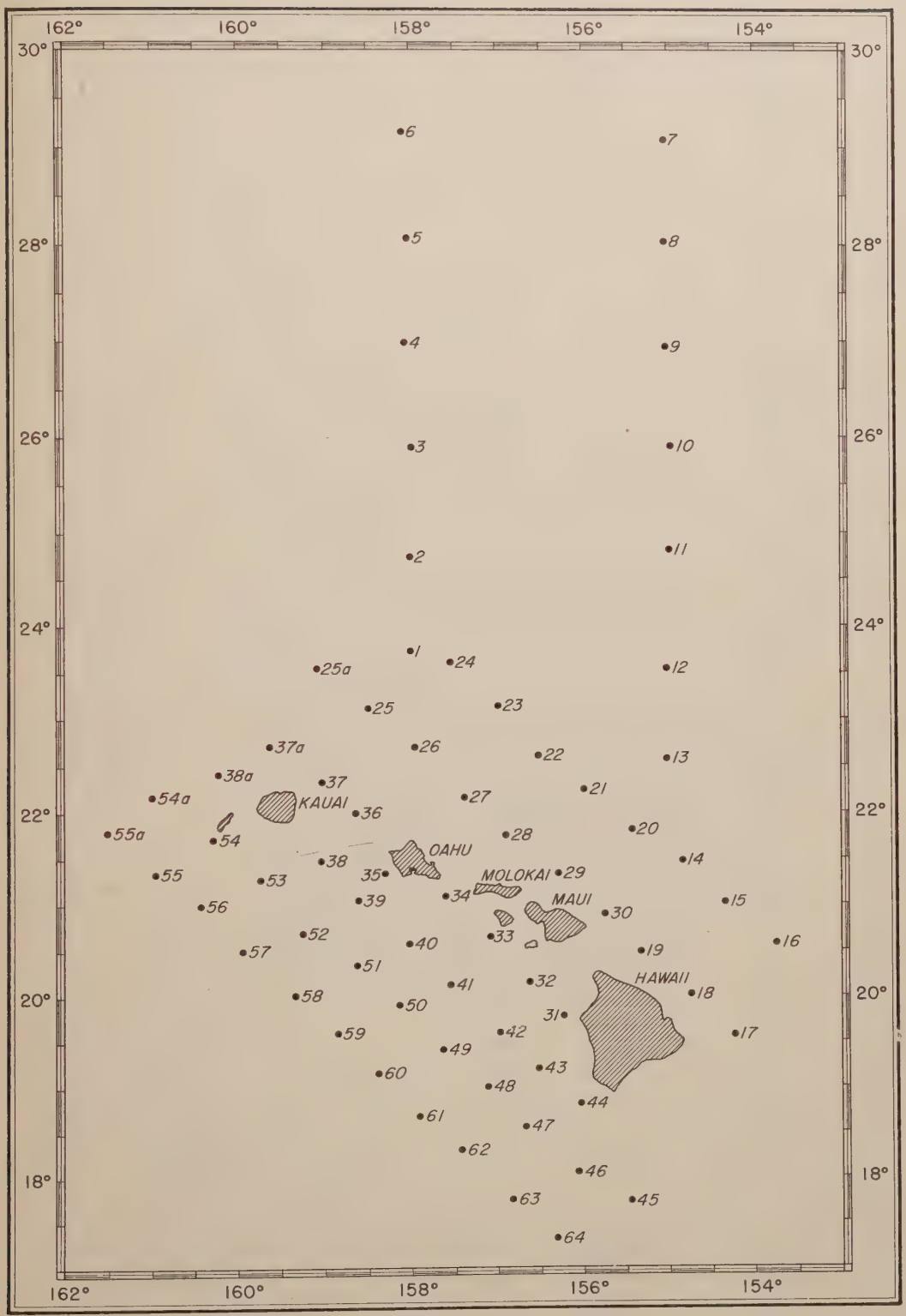

Figure 11.--Station positions, H. M. Smith cruise 20, March 1953.

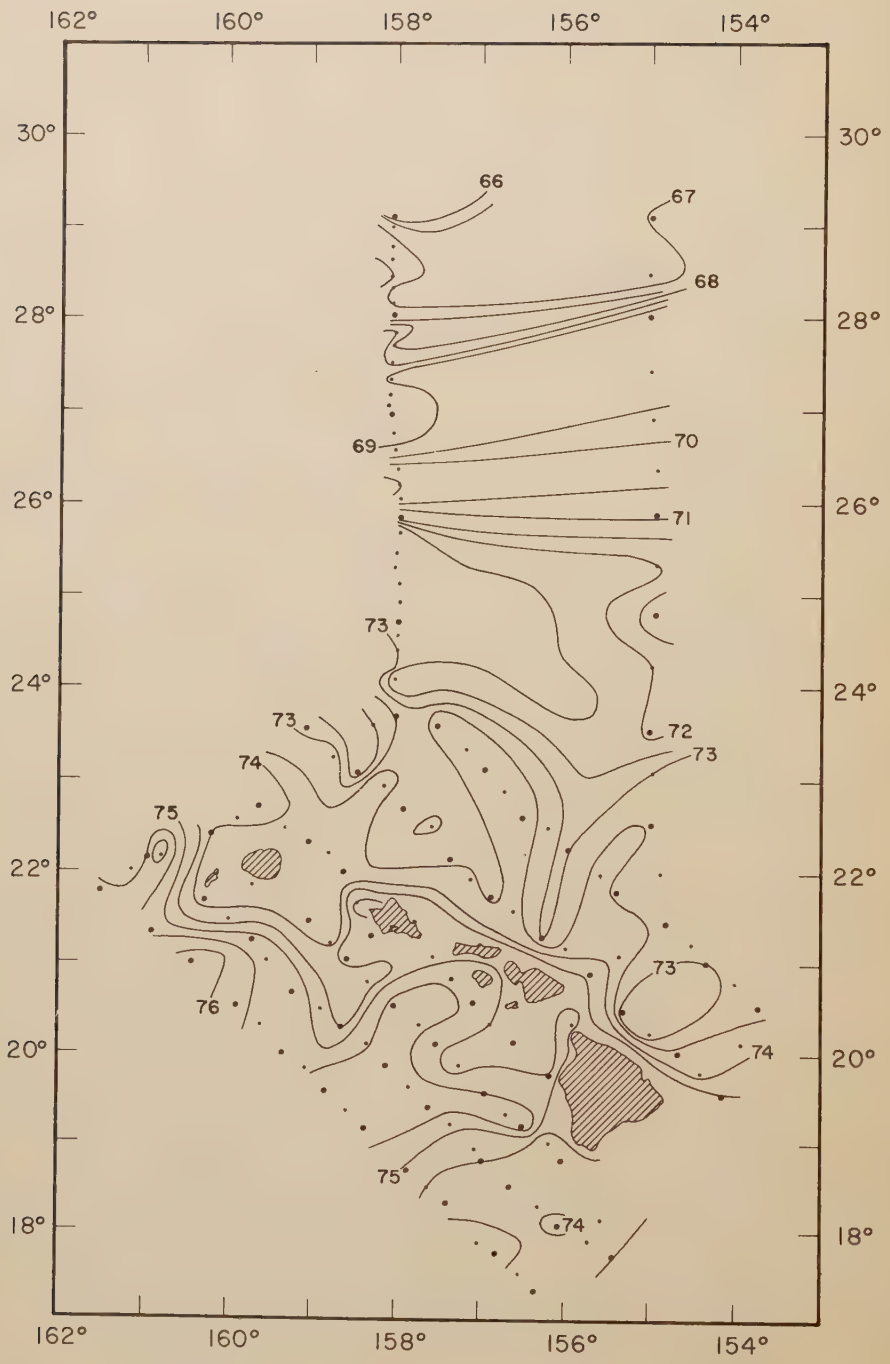

Figure 12.--Surface bucket temperatures in °F., with contour intervals of 0.5°F. H. M. Smith cruise 20, March 1953.

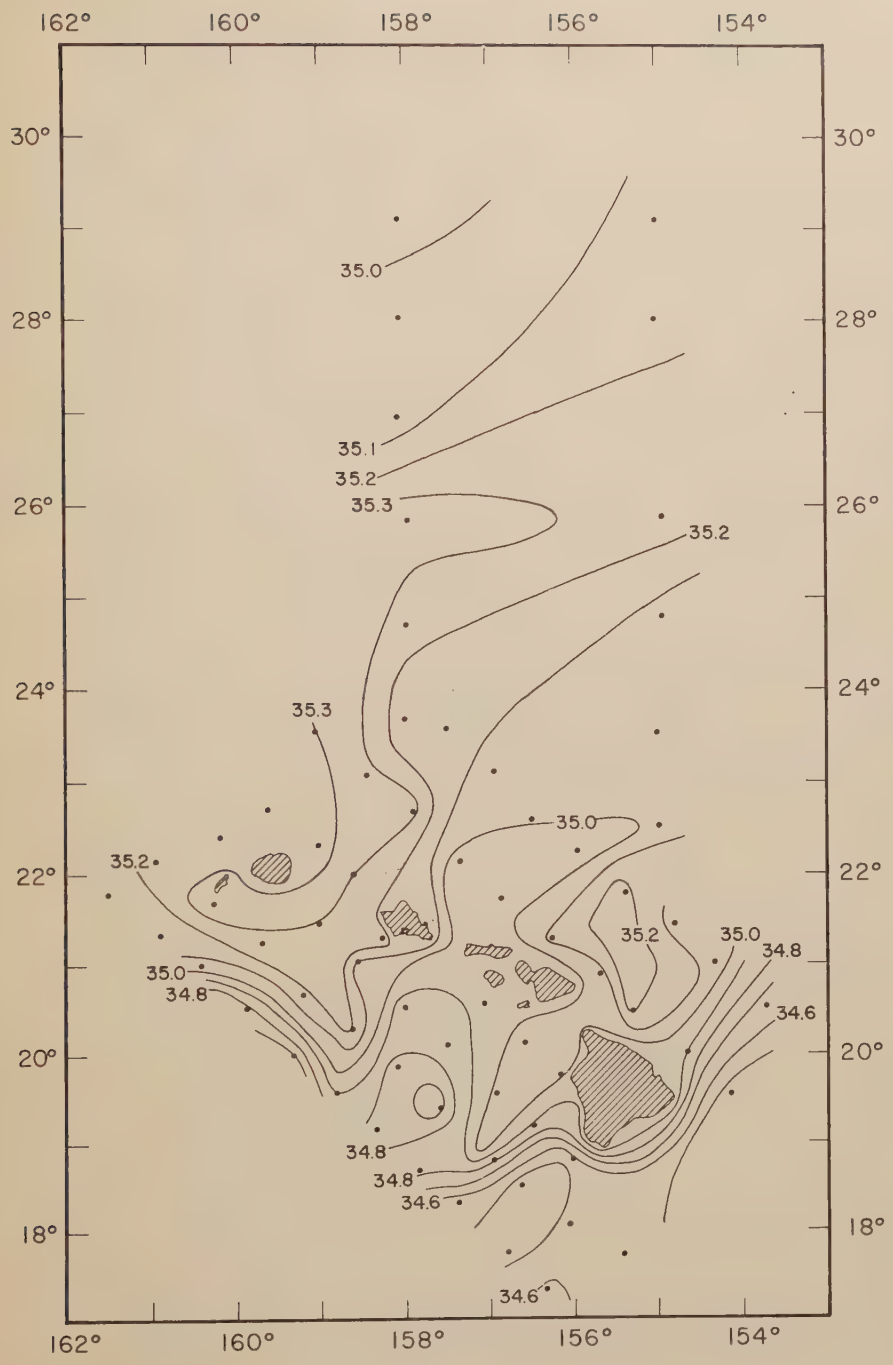

Figure 13.--Surface salinity in °/oo, H. M. Smith cruise 20, March 1953. Contour interval 0.1 °/oo.

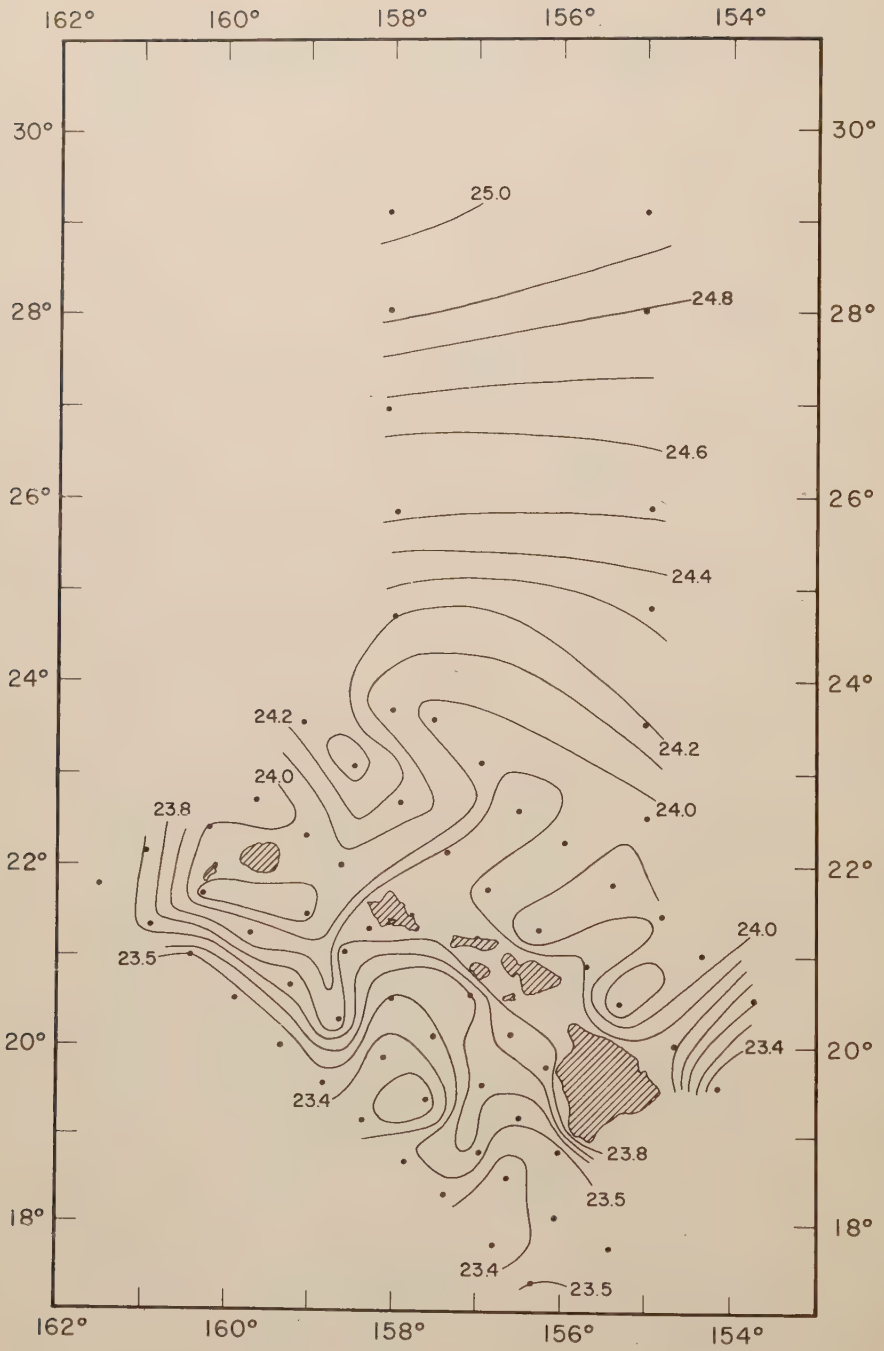

Figure 14.--Surface density (sigma-t), H. M. Smith cruise 20, March 1953. Contour interval 0.1.

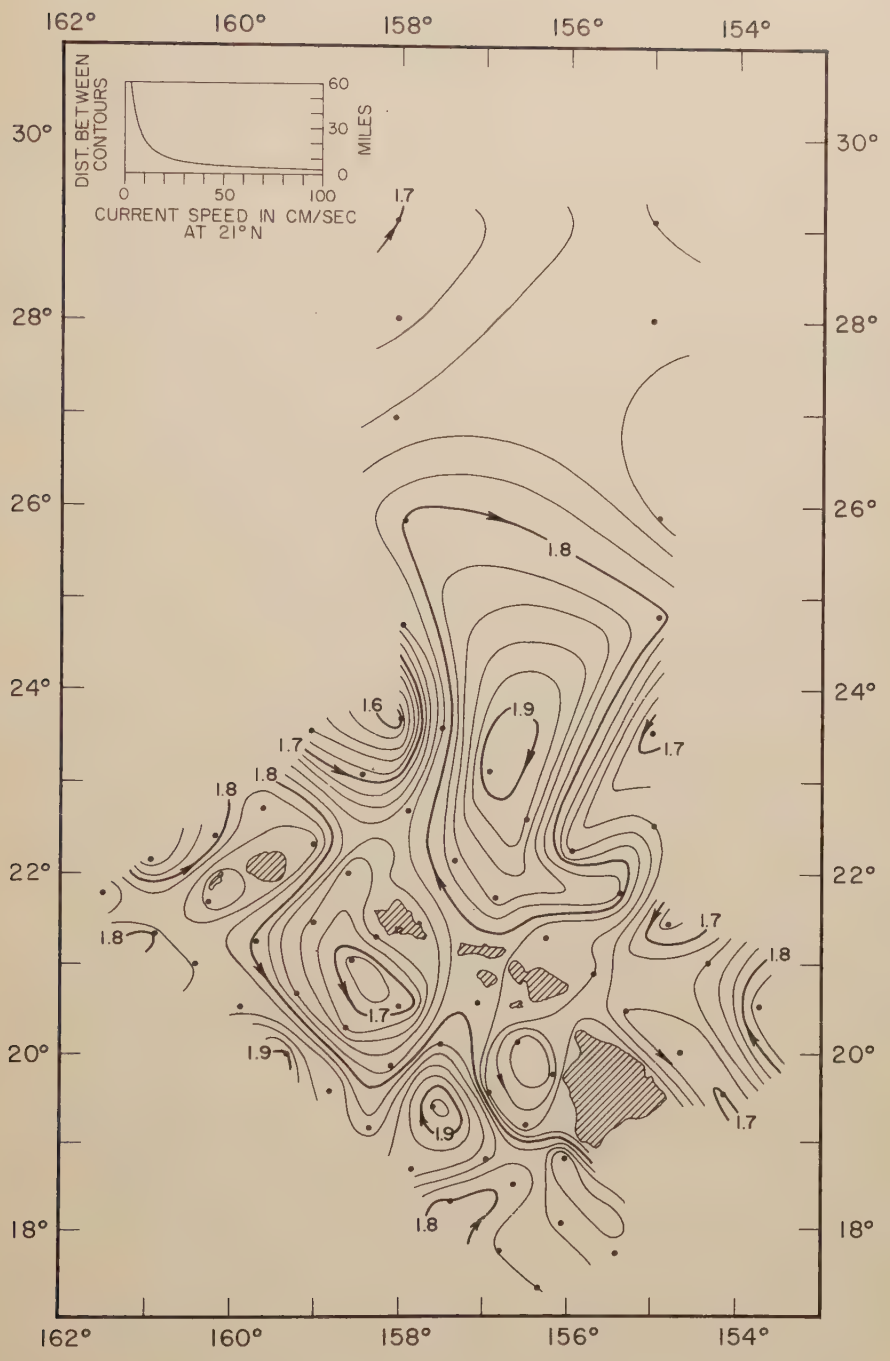

Figure 15.--Dynamic height anomalies (dynamic meters) at the surface relative to 1,000 m., H. M. Smith cruise 20, March 1953. Contour interval 0.02 dynamic meters.

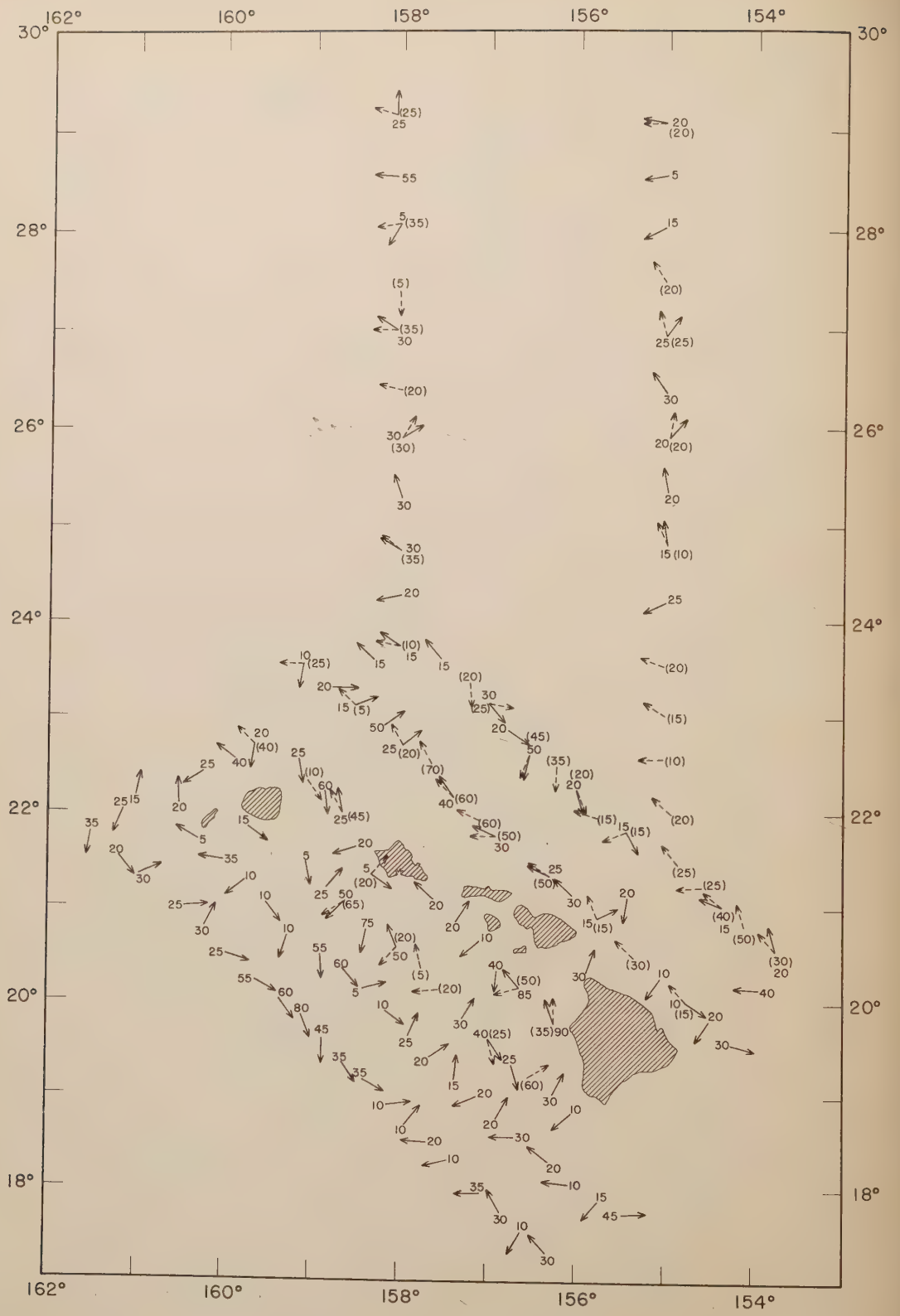

Figure 16.--Geomagnetic electrokinetograph (GEK) current speeds in cm./sec. and directions, H. M. Smith cruise 20, March 1953. Dashed arrows and numbers in parentheses indicate observations with floated electrodes.

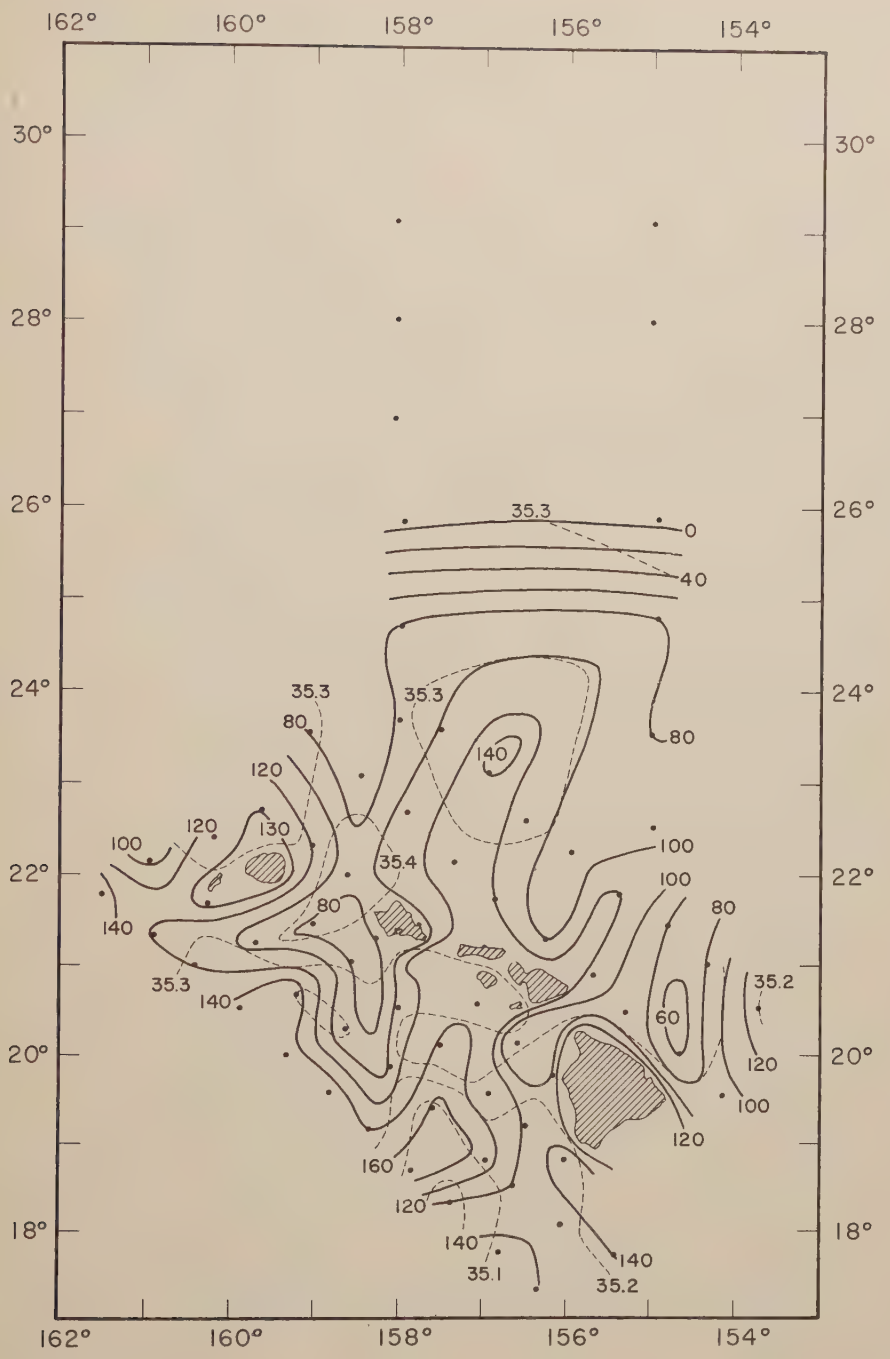

Figure 17.--Bathymetric chart (depth in meters) of the 24.5 sigma-t surface, H. M. Smith cruise 20, March 1953. Contour interval 20 m. Dashed lines indicate the salinity (^{o}/oo) distribution on the surface with contour intervals of 0.1 ^{o}/oo.

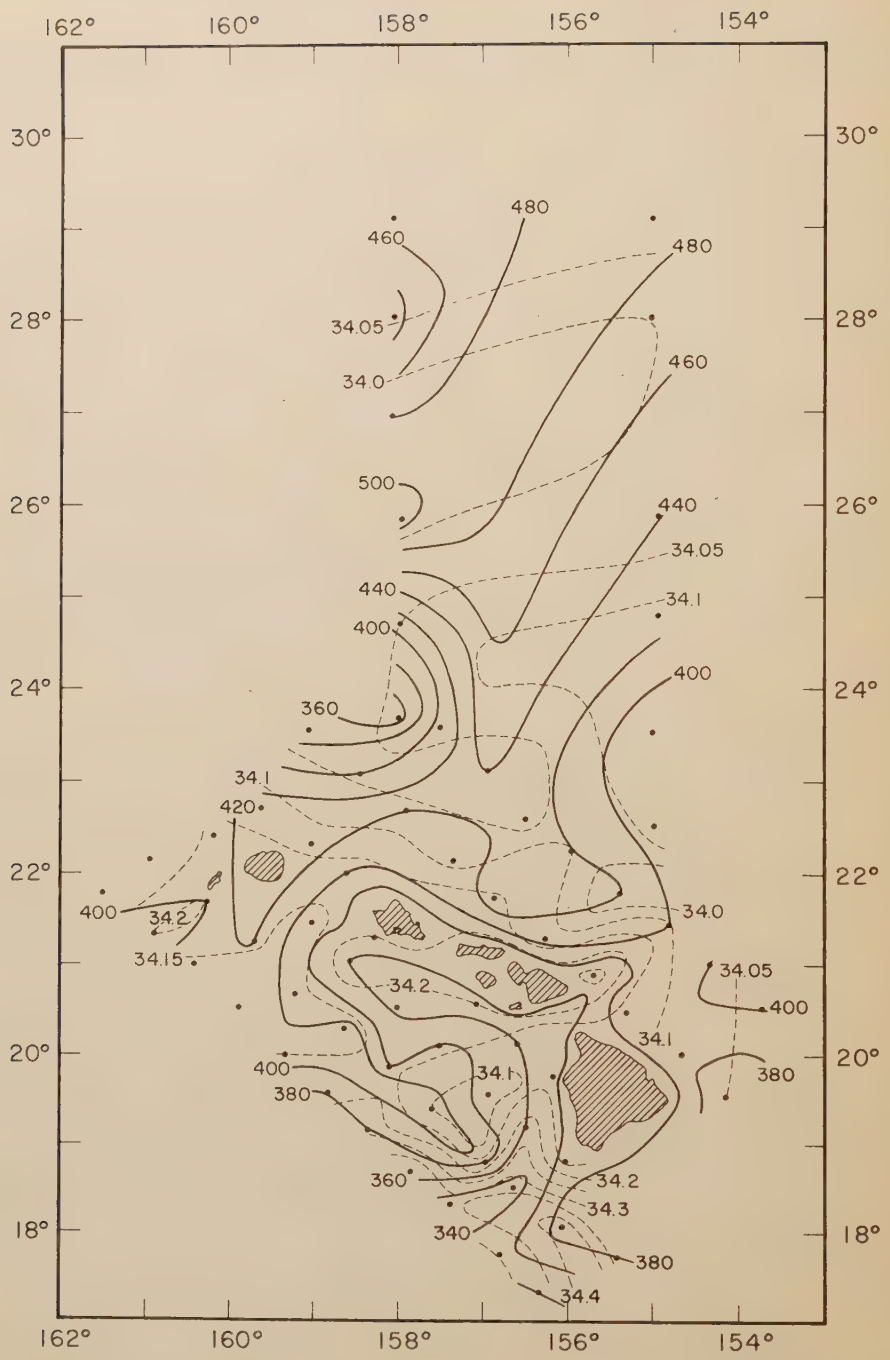

Figure 18.--Bathymetric chart (depth in meters) of the 26.5 sigma-t surface, H. M. Smith cruise 20, March 1953. Contour interval 20 m. Dashed lines indicate the salinity (^{o}/oo) distribution on the surface with contour intervals of 0.05 ^{o}/oo.

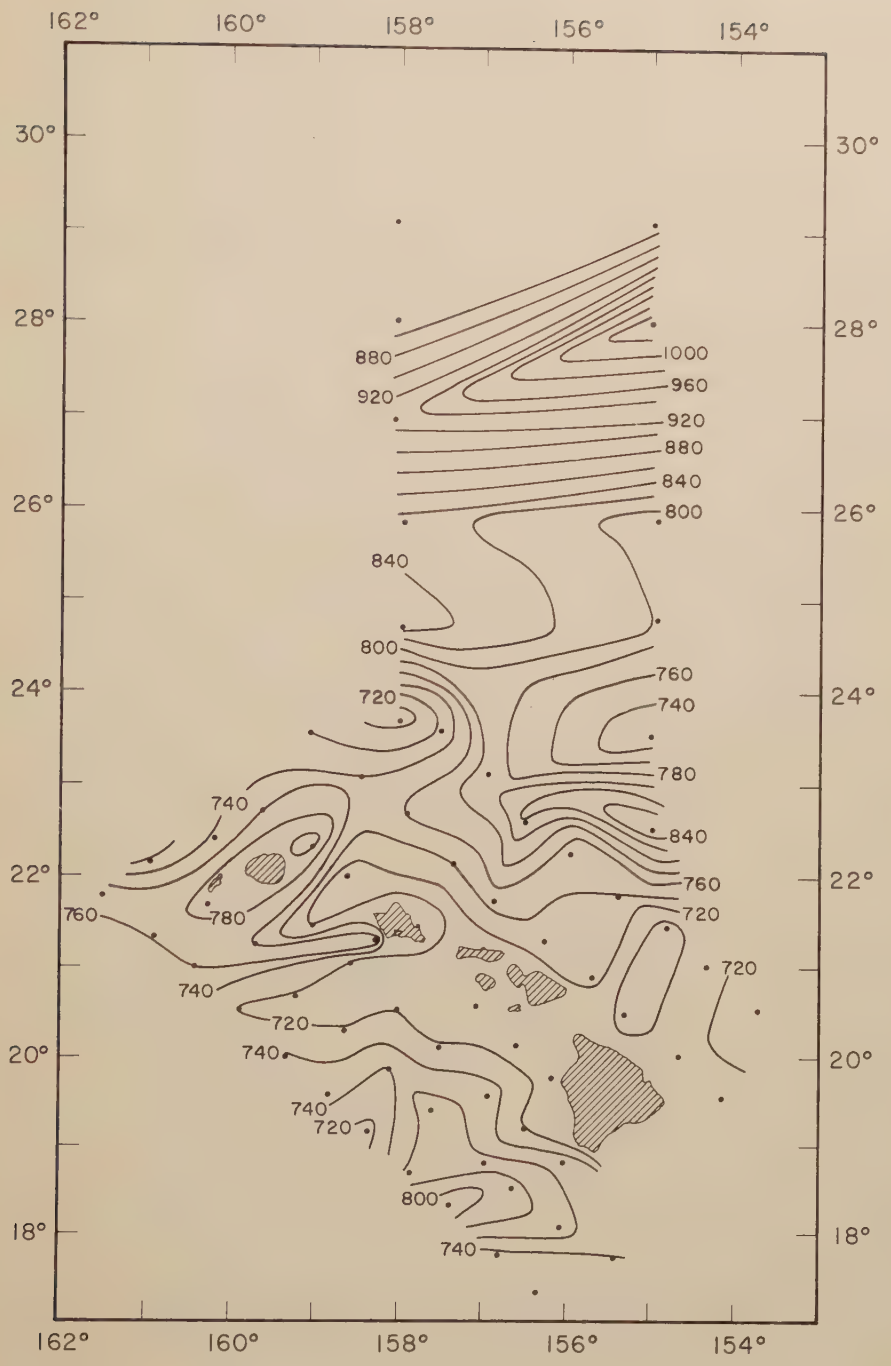

Figure 19.--Bathymetric chart (depth in meters) of the 27.2 sigma-t surface, H. M. Smith cruise 20, March 1953. Contour interval 20 m.

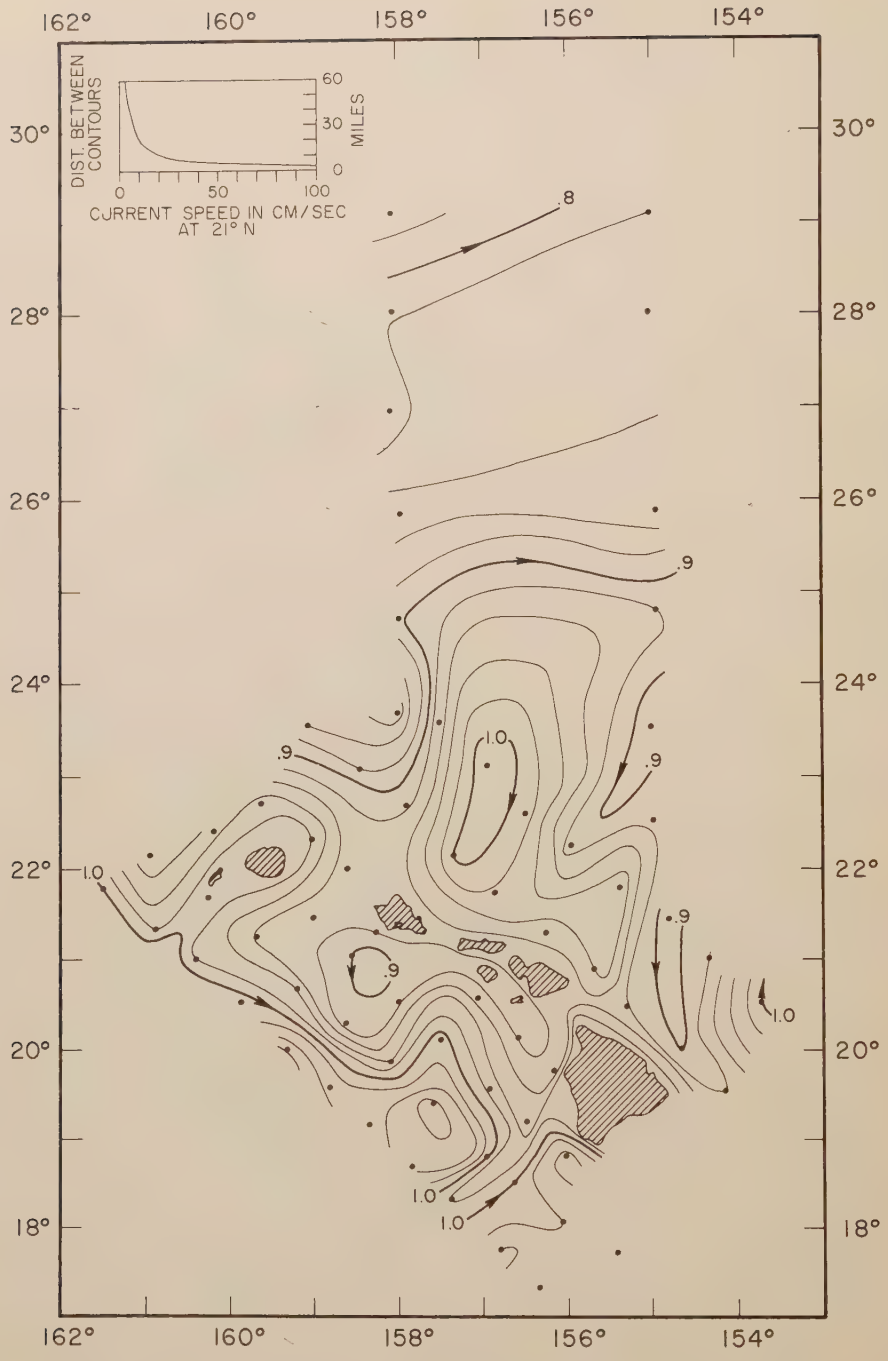

Figure 20.--Dynamic height anomalies (dynamic meters) at the surface relative to 300 m., H. M. Smith cruise 20, March 1953. Contour interval 0.02 dynamic meters.

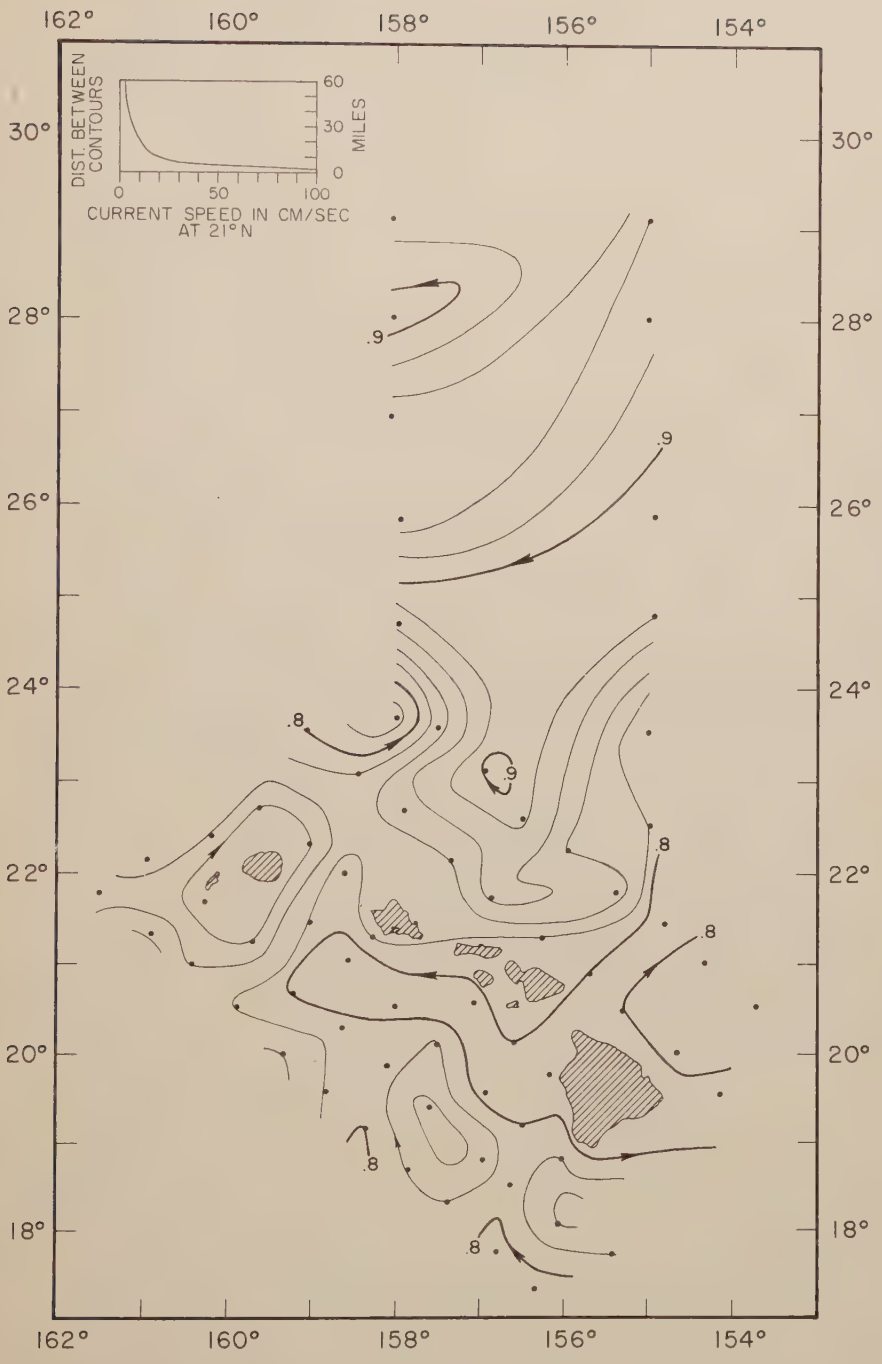

Figure 21.--Dynamic height anomalies (dynamic meters) at 300 m. relative to 1,000 m., H. M. Smith cruise 20, March 1953. Contour interval 0.02 dynamic meters.

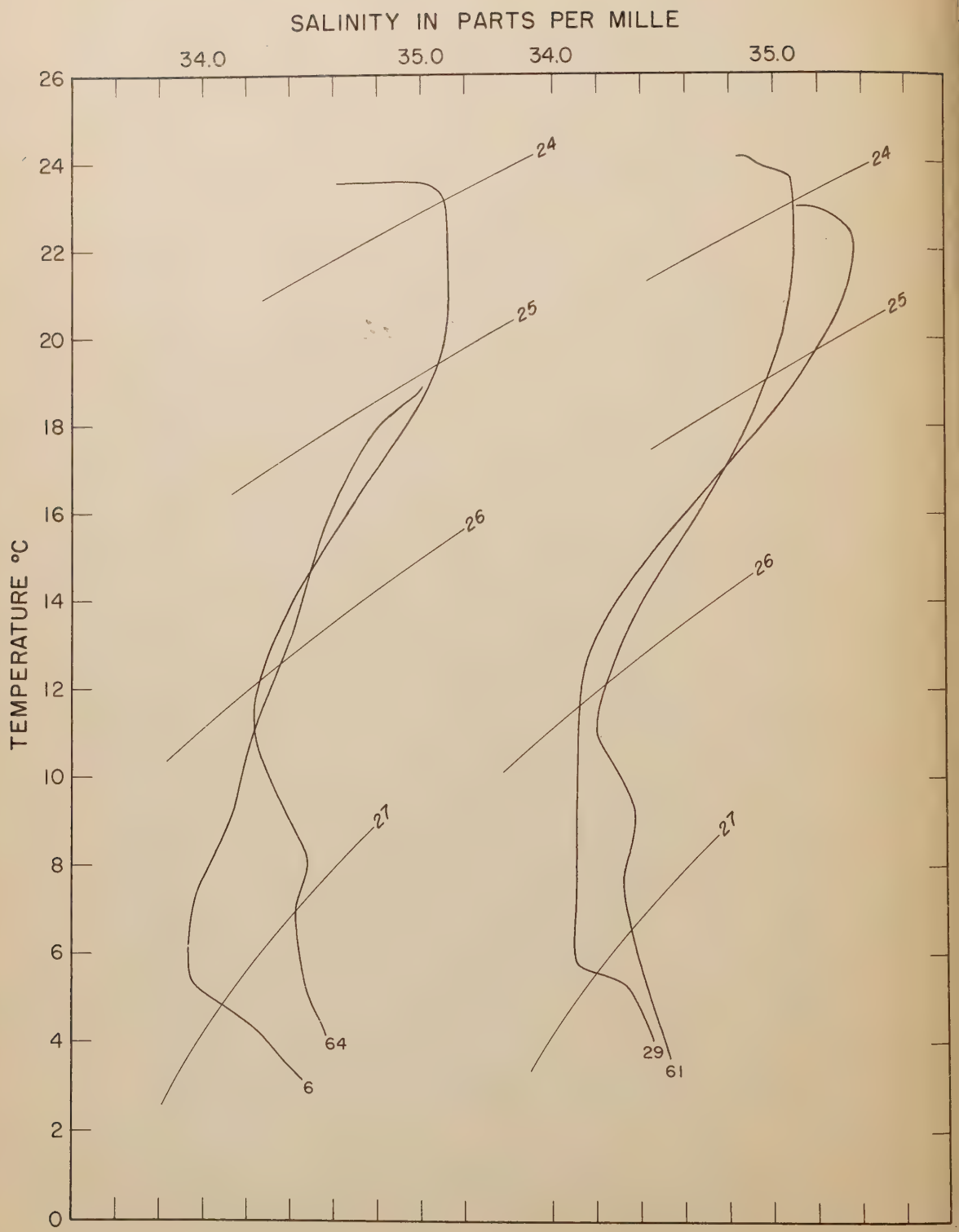

Figure 22.--Temperature-salinity curves for stations 6, 64, 29, and 61, H. M. Smith cruise 20, March 1953.

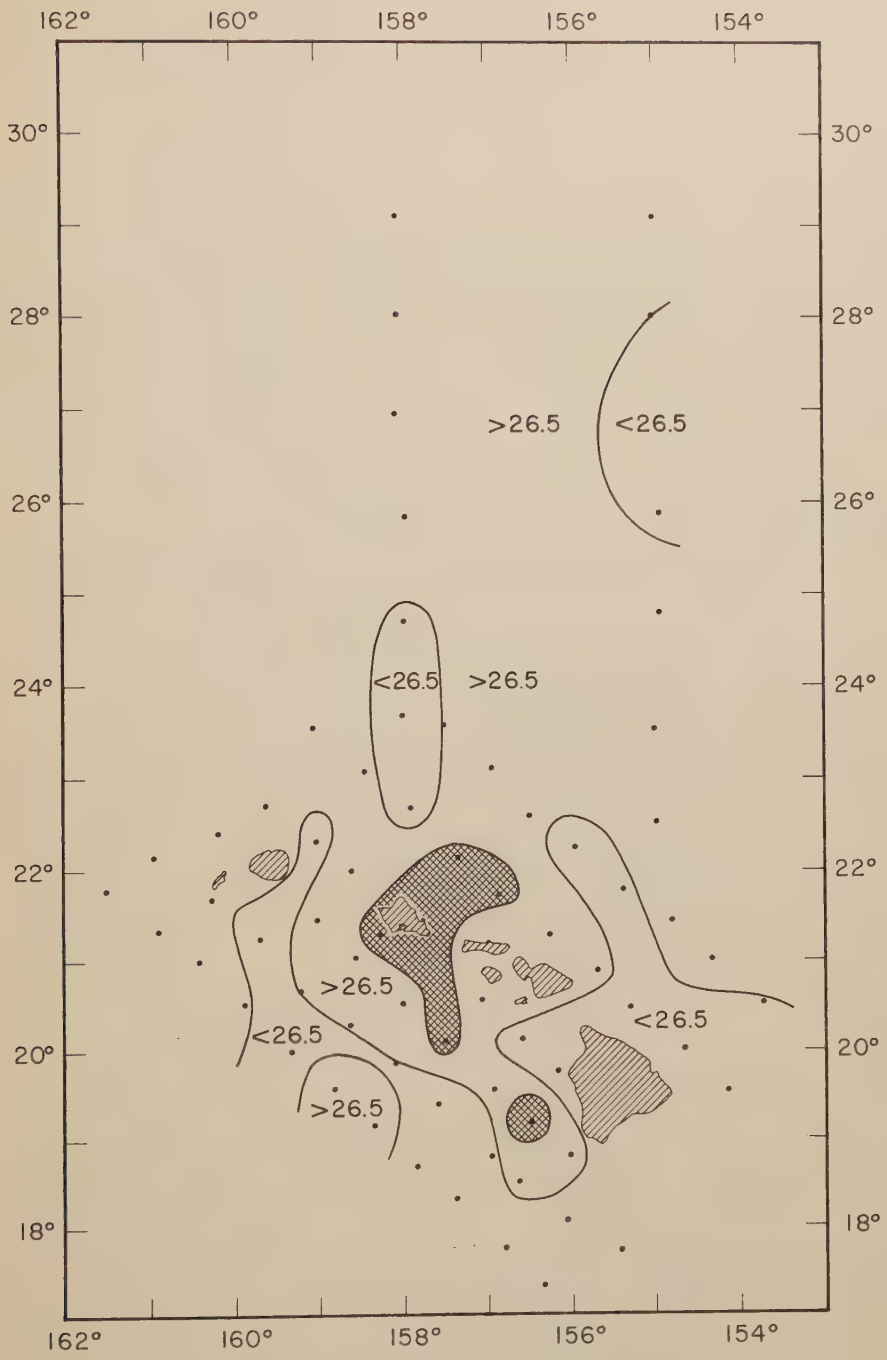

Figure 23.--Schematic diagram of the density (sigma-t) distribution on the salinity minimum layer separated into regions where the sigma-t is greater and less than 26.5. H. M. Smith cruise 20, March 1953. Cross-hatched zones include stations of constant salinity throughout a sigma-t range of 26.1 to 26.8.

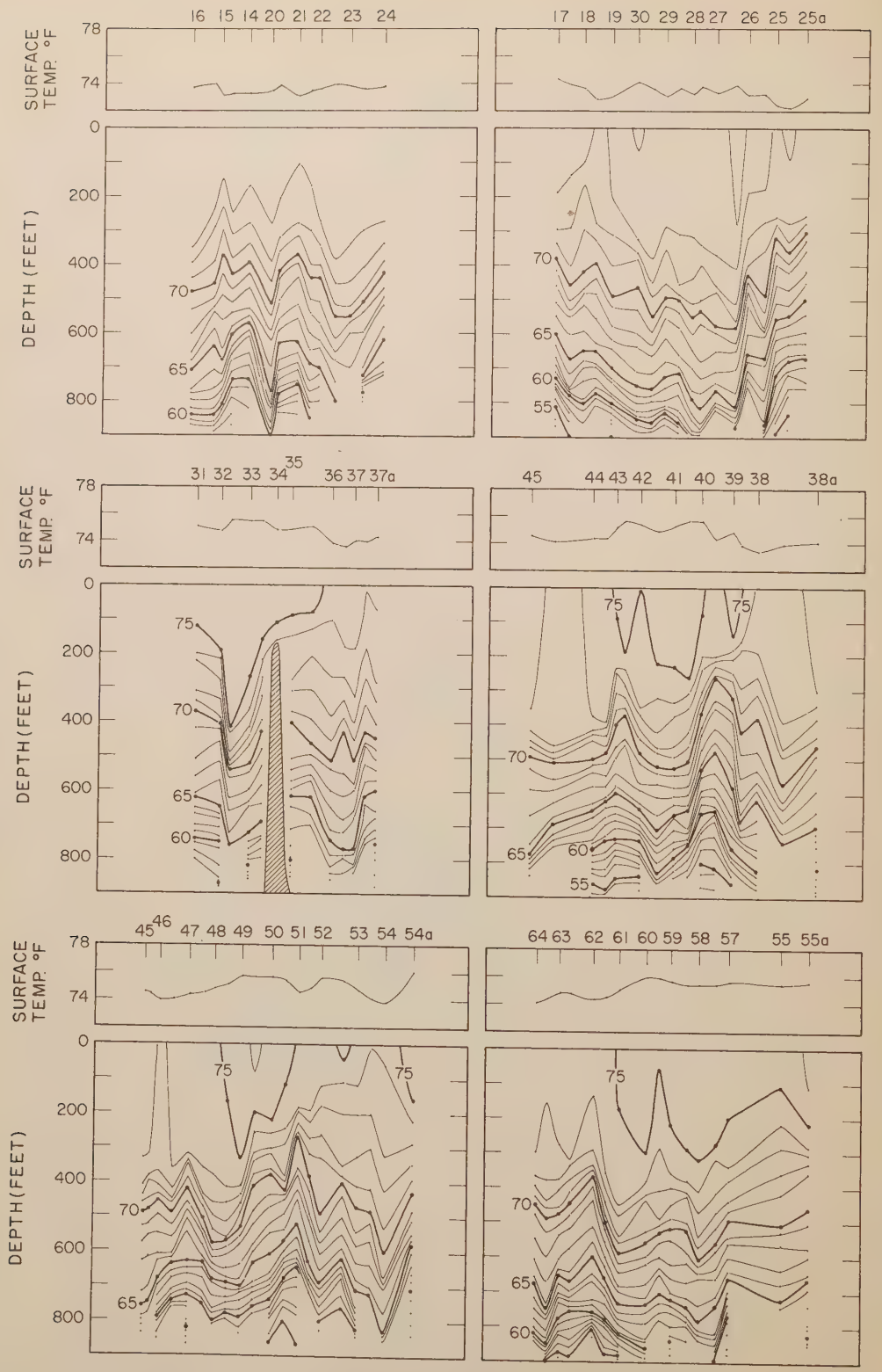

Figure 24.--Vertical bathythermograph temperature (°F.) sections from stations 24 to 16, 25a to 17, 37a to 31, 38a to 45, 54a to 45, and 55a to 64, H. M. Smith cruise 20, March 1953. The upper panels show the surface bucket temperatures in °F.

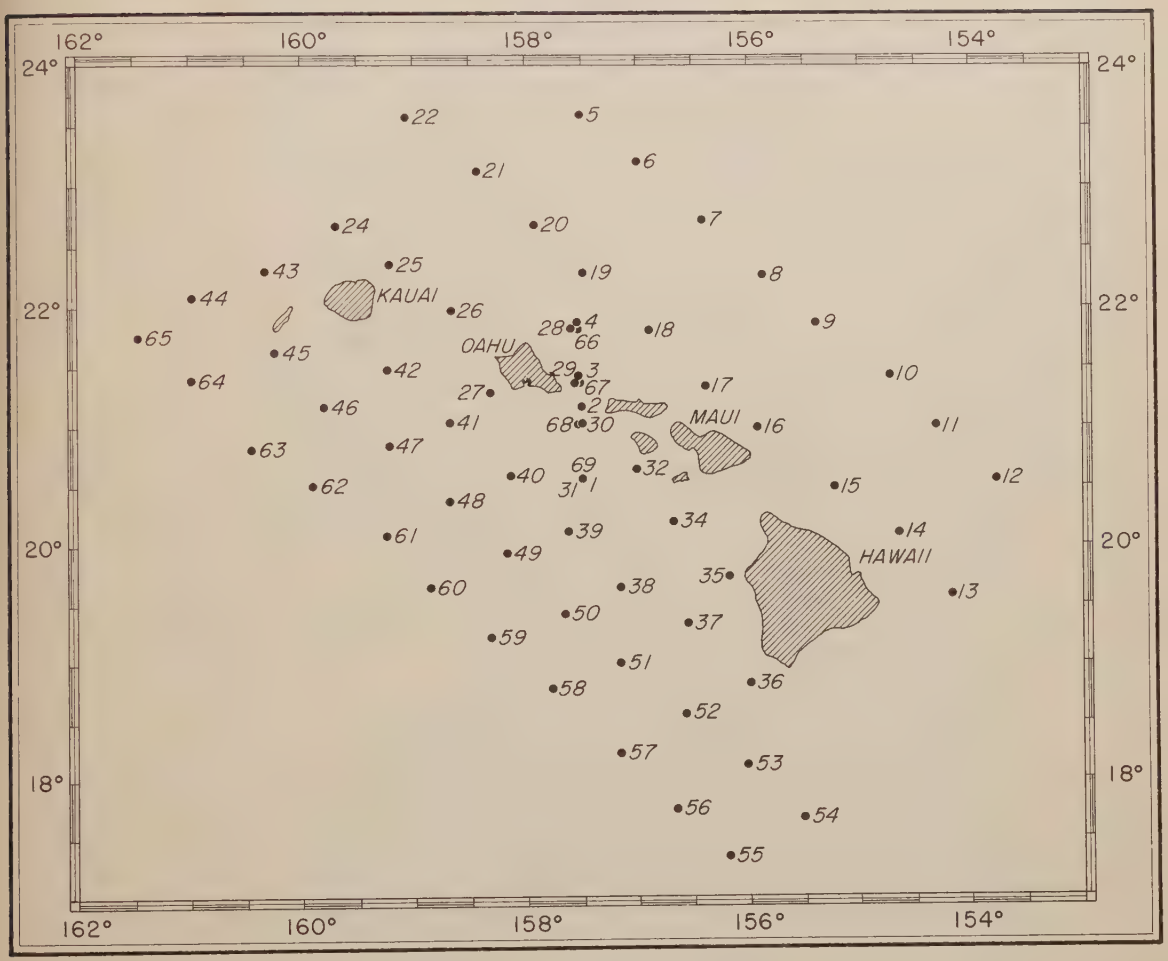

Figure 25.--Station positions, H. M. Smith cruise 21, August 1953.

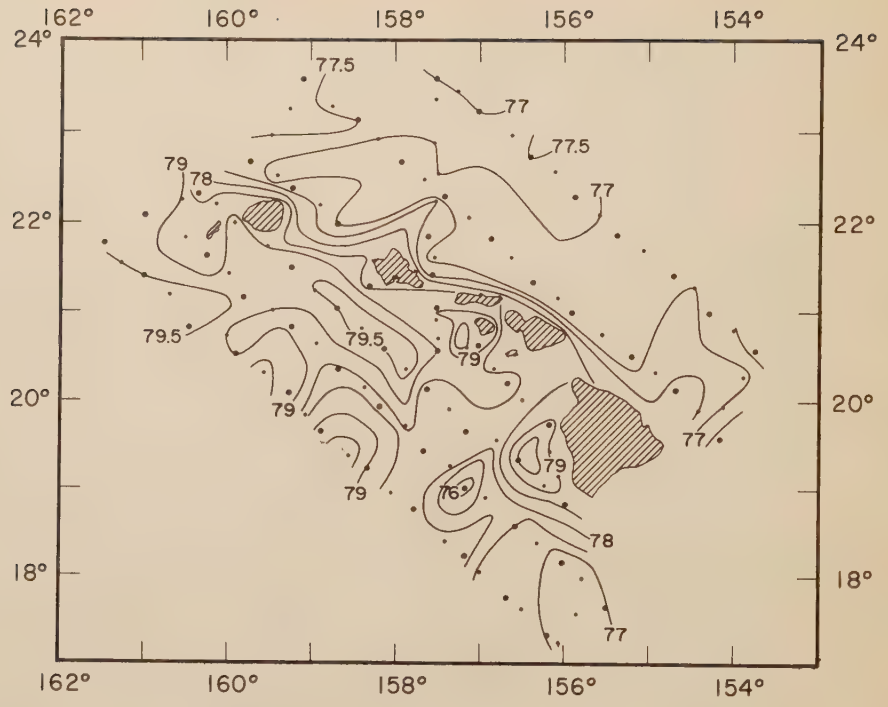

Figure 26.--Surface bucket temperatures in °F. with contour intervals of 0.5°F. H. M. Smith cruise 21, August 1953.

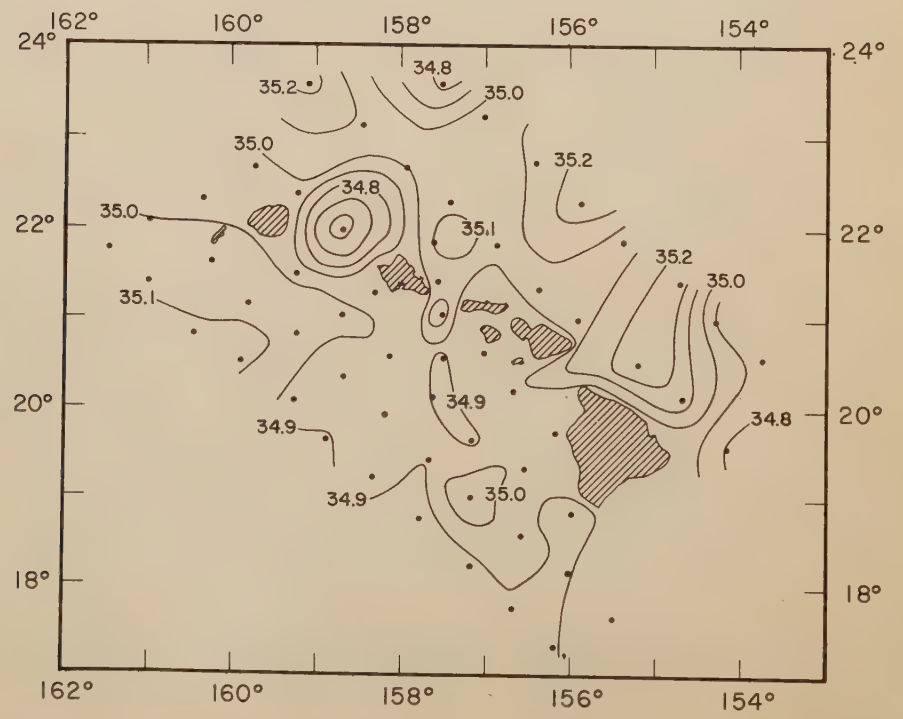

Figure 27.--Surface salinity in °/oo, H. M. Smith cruise 21, August 1953. Contour interval 0.1 °/oo.

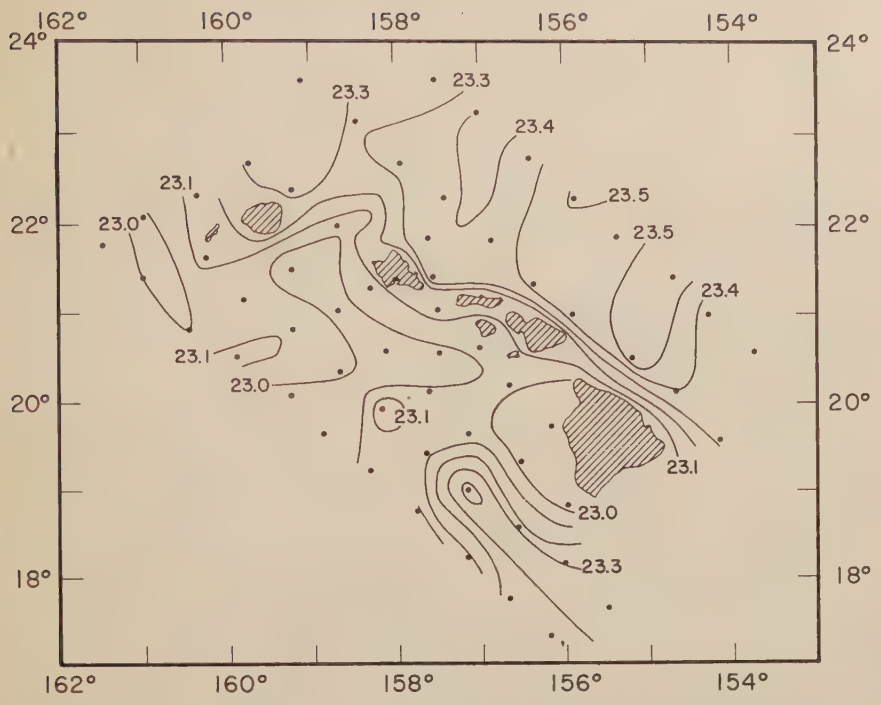

Figure 28.--Surface density (sigma-t), H. M. Smith cruise 21, August 1953. Contour interval 0.1.

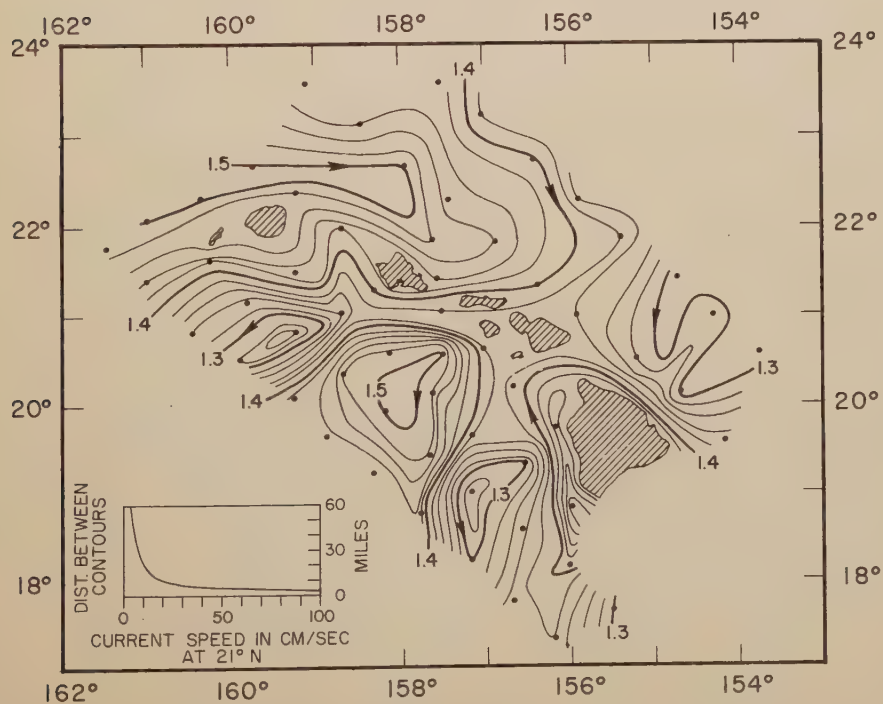

Figure 29.--Dynamic height anomalies (dynamic meters) at the surface relative to 500 m., H. M. Smith cruise 21, August 1953. Contour interval 0.02 dynamic meters.

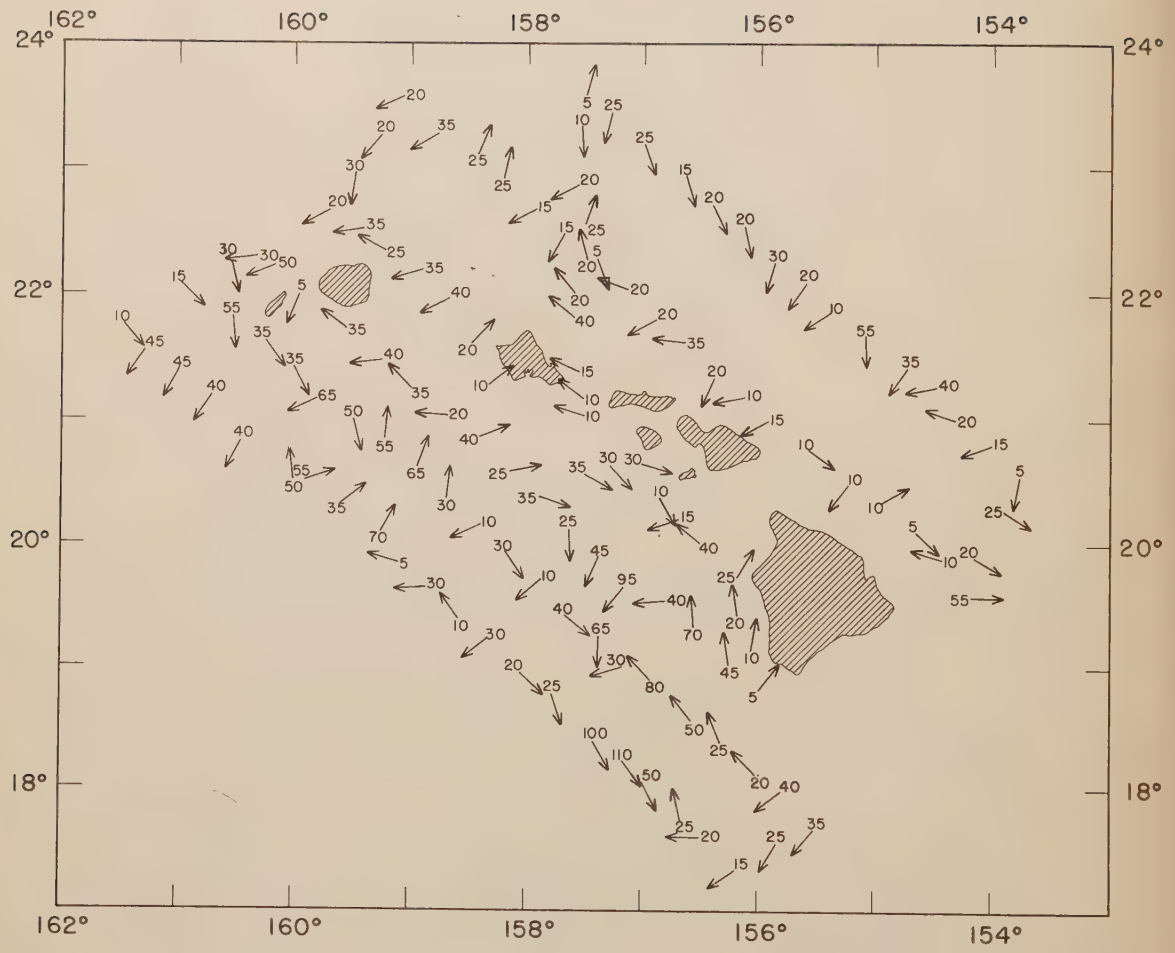

Figure 30.--Geomagnetic electrokinetograph (GEK) current speeds in cm./sec. and directions, H. M. Smith cruise 21, August 1953.

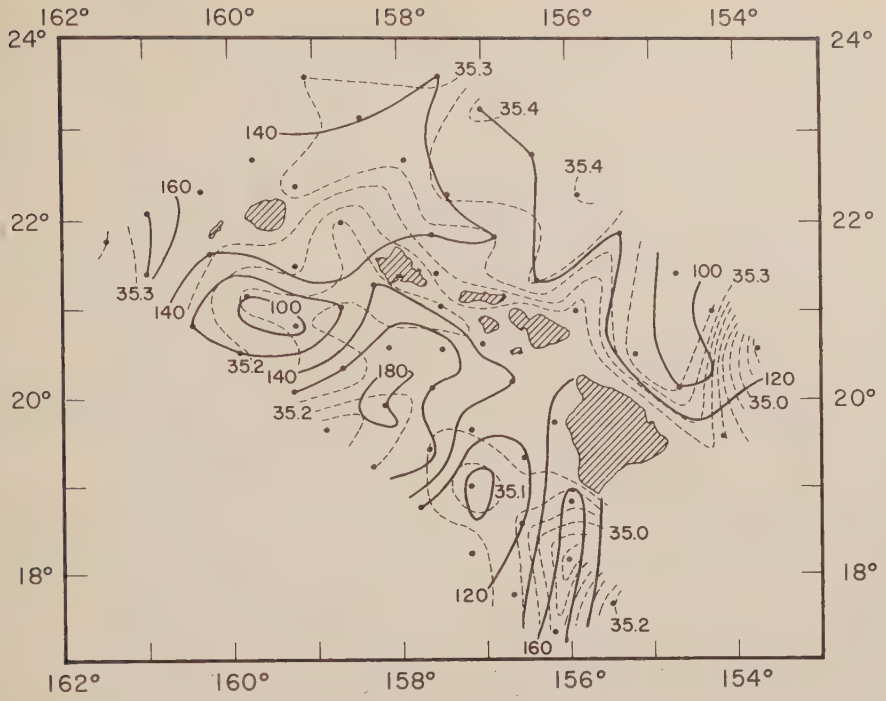

Figure 31.--Bathymetric chart (depth in meters) of the 24.5 sigma-t surface, H. M. Smith cruise 21, August 1953. Contour interval 20 m. Dashed lines indicate the salinity (°/oo) distribution on the surface with contour intervals of 0.05 °/oo.

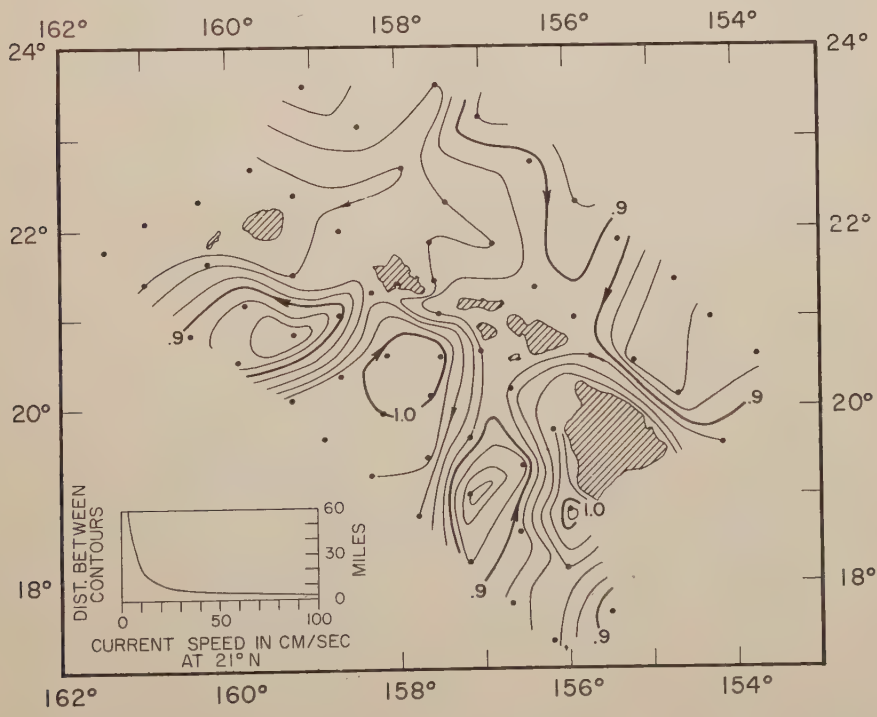

Figure 32.--Dynamic height anomalies (dynamic meters) at the surface relative to 250 m., H. M. Smith cruise 21, August 1953. Contour interval 0.02 dynamic meters.

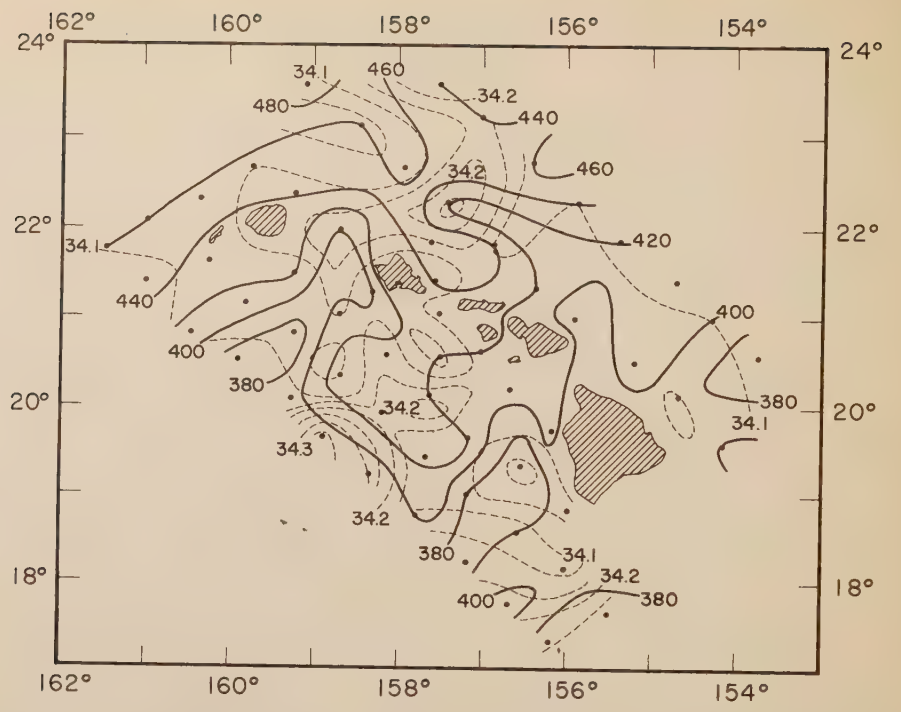

Figure 33.--Bathymetric chart (depth in meters) of the 26.5 sigma-t surface, H. M. Smith cruise 21, August 1953. Contour interval 20 m. Dashed lines indicate the salinity ($^{o}/_{oo}$) distribution on the surface with contour intervals of 0.05 $^{o}/_{oo}$.

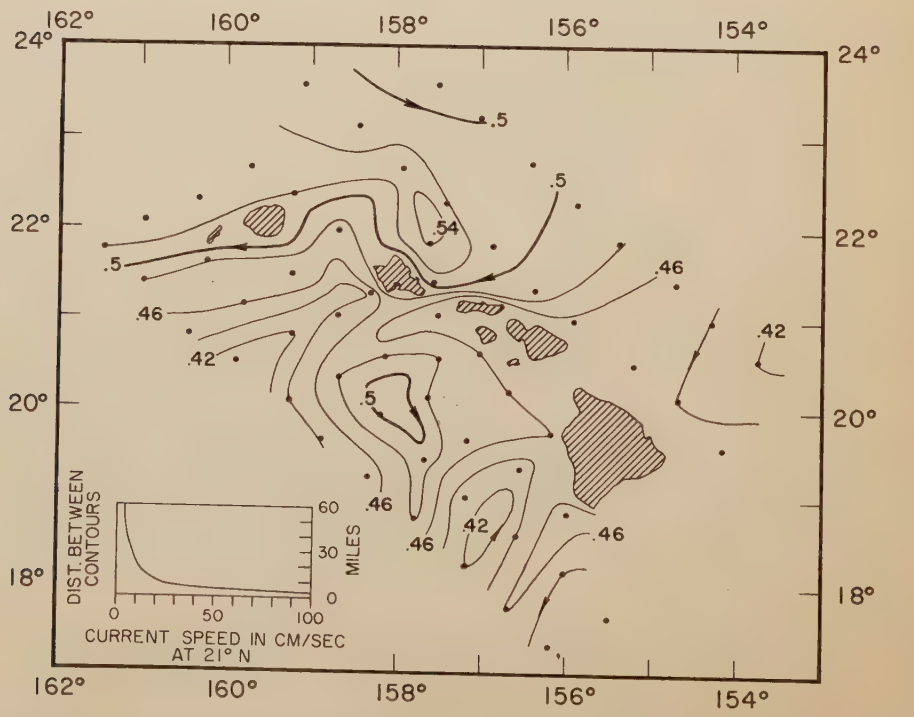

Figure 34.--Dynamic height anomalies (dynamic meters) at 250 m. relative to 500 m., H. M. Smith cruise 21, August 1953. Contour interval 0.02 dynamic meters.

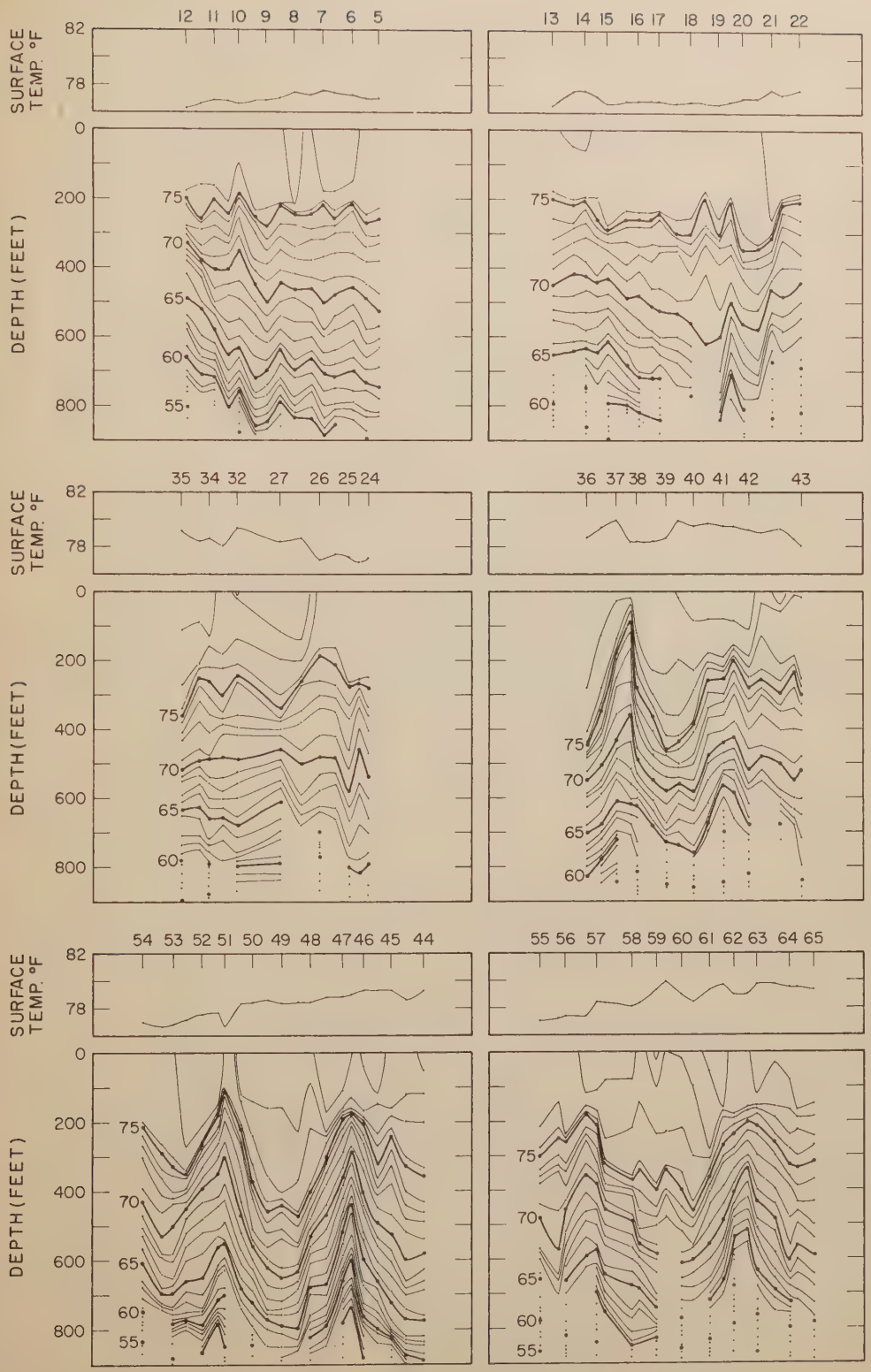

Figure 35.--Vertical bathythermograph temperature (°F.) sections from stations 5 to 12, 22 to 13, 24 to 35, 43 to 36, 44 to 54, and 65 to 55, H. M. Smith cruise 21, August 1953. The upper panels show the surface bucket temperatures in °F.

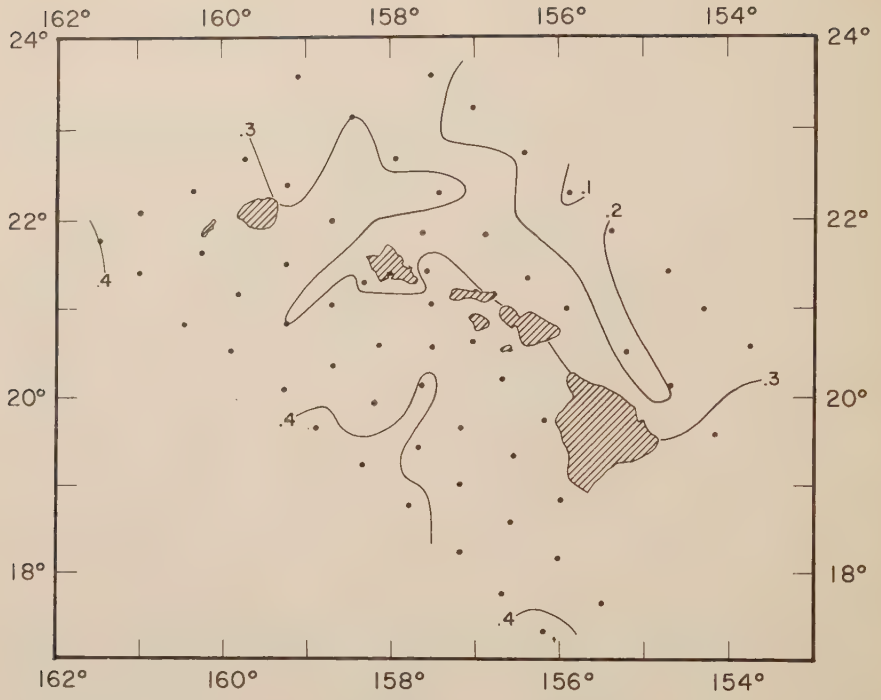

Figure 36.--Surface phosphate-phosphorus distribution in μg-at/l, H. M. Smith cruise 21, August 1953. Contour interval 0.1 μg-at/l.

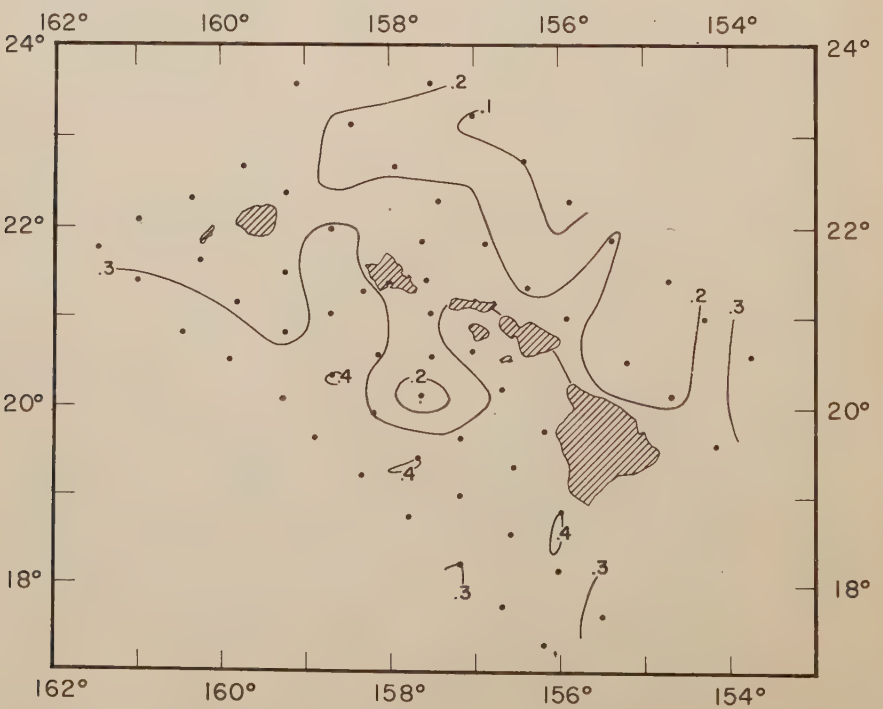

Figure 37.--Phosphate-phosphorus distribution (μg-at/l) on the 24.5 sigma-t surface, H. M. Smith cruise 21, August 1953. Contour interval 0.1 μg-at/l.

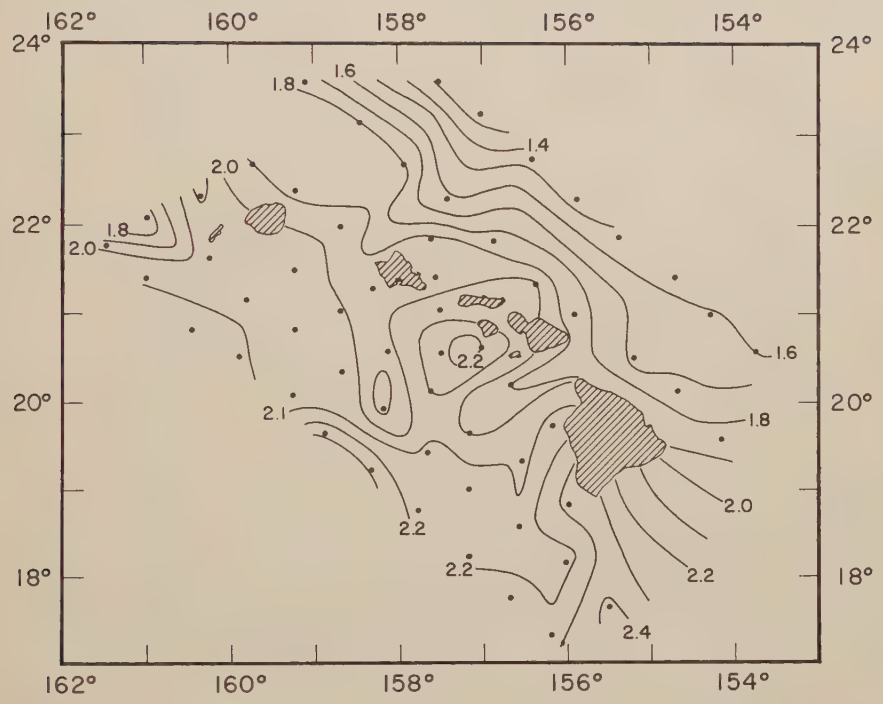

Figure 38.--Phosphate-phosphorus distribution (μg-at/l) on the 26.5 sigma-t surface, H. M. Smith cruise 21, August 1953. Contour interval 0.1 μg-at/l.

APPENDIX

Tabulations of oceanographic data for Hugh M. Smith cruises 17, 20, 21, 2

Personnel:

Captains:

Hugh M. Smith cruise 17 - R. Johnson
Hugh M. Smith cruise 20 - R. Johnson
Hugh M. Smith cruise 21 - G. Wilkinson
Hugh M. Smith cruise 26 - J. Sutherland

Field Party Chiefs:

Hugh M. Smith cruise 17 - J. King
Hugh M. Smith cruise 20 - T. Cromwell
Hugh M. Smith cruise 21 - E. D. Stroup
Hugh M. Smith cruise 26 - D. Yamashita

In charge of data computations and tabulations - Mrs. M. L. Godfrey

Remarks about the data tabulations:

Weather was recorded according to the WW code in the U. S. Weather Bureau Circular M, Instructions to Marine Meteorological Observers.

Wind velocity was measured by an anemometer located 30 m. above the sea surface.

In the tabulated data, the horizontal line(s) between depths separates the two or more casts necessary during the particular station.

When the interpolated and calculated values are shown for greater depths than the observed values, they were obtained by extrapolation using the data from adjoining stations as a guide.

Measurements of temperature, chemical determinations of salinity, oxygen, and phosphate were made in duplicate and averaged if the values were within the following limits: temperature, above 300 m., 0.05°C., below 300 m., 0.02°C.; salinity 0.04 °/oo; oxygen 0.1 ml/l; phosphate 0.05 µg-at/l. Whenever these limits are exceeded, both values are carried in the tabulations. Obviously wrong values, as determined from the station curves, are omitted from the tabulations.

STATION 1

M/V Hugh M. Smith: Cruise 17, 20°20'N, 159°14'W, September 6, 1952. Messenger time: 1237 GCT. Weather: 15, cloud coverage 10. Wind: 130°, 14 kt. Sea: 1-3 ft. Wire angle: 10°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
05	26.71	34.97	22.81		
28	25.96	35.13	23.16		
52	24.52	34.92	23.45		
100	22.81	35.16	24.13		
148	20.52	35.16	24.76		
196	17.61	34.83	25.25		
243	14.31	34.45	25.72		
291	11.36	34.24	26.14		
338	09.38	34.17	26.43		
387	08.02	34.15	26.62		
482	06.62	34.22	26.88		
578	05.63	34.29	27.06		
675	05.08	34.36	27.18		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.71	34.97	22.80	0.000	1.417
10	26.71	34.97	22.80	0.051	1.366
20	26.60	35.03	22.88	0.101	1.316
30	25.93	35.13	23.17	0.149	1.268
50	24.61	35.12	23.57	0.240	1.177
75	23.78	35.13	23.82	0.346	1.071
100	22.81	35.16	24.12	0.445	0.972
150	20.41	35.16	24.79	0.621	0.796
200	17.42	34.81	25.28	0.771	0.646
250	13.88	34.41	25.77	0.897	0.520
300	10.92	34.22	26.20	1.002	0.415
400	07.80	34.15	26.65	1.169	0.248
500	06.42	34.23	26.91	1.303	0.114
600	05.45	34.31	27.09	1.417	0.000

STATION 2

M/V Hugh M. Smith: Cruise 17, 21°11'N, 159°17'W,
September 6, 1952. Messenger time: 1937 GCT.
Weather: 02, cloud coverage 6. Wind: 070°, 11 kt.
Sea: 3-5 ft. Wire angle: 08°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
03	26.04	35.13	23.14		
28	26.02	35.13	23.14		
52	24.16	35.10	23.69		
99	22.02	35.13	24.33		
147	20.17	35.11	24.82		
195	17.43	34.80	25.28		
243	14.06	34.41	25.74		
290	11.30	34.21	26.12		
338	09.92	34.16	26.33		
386	08.65	34.14	26.52		
482	07.03	34.17	26.78		
578	06.10	34.28	26.99		
676	05.56	34.35	27.11		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.04	35.13	23.14	0.000	1.416
10	26.03	35.13	23.14	0.047	1.369
20	26.02	35.13	23.14	0.095	1.321
30	26.00	35.13	23.15	0.142	1.274
50	24.28	35.10	23.65	0.232	1.184
75	23.25	35.10	23.95	0.336	1.080
100	22.00	35.13	24.33	0.431	0.985
150	20.01	35.10	24.85	0.601	0.815
200	17.41	34.80	25.28	0.749	0.667
250	13.50	34.36	25.81	0.874	0.542
300	10.98	34.20	26.17	0.979	0.437
400	08.39	34.14	26.56	1.152	0.264
500	06.83	34.19	26.82	1.295	0.121
600	05.92	34.30	27.03	1.416	0.000

STATION 3

M/V Hugh M. Smith: Cruise 17, 21°43'N, 159°16'W,
September 7, 1952. Messenger time: 0107 GCT.
Weather: 02, cloud coverage 3. Wind: 060°, 22 kt.
Sea: 3-5 ft. Wire angle: 35°. Depth of water: 1800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.13	35.06	23.06		
19	26.10	35.08	23.08		
37	25.97	35.07	23.11		
72	24.07	35.18	23.78		
107	22.44	35.15	24.23		
142	21.56	35.16	24.48		
179	18.78	34.97	25.07		
214	16.68	34.70	25.38		
250	14.29	34.46	25.73		
285	11.70	34.23	26.07		
357	08.90	34.16	26.50		
429	07.86	34.15	26.65		
502	06.82	34.21	26.84		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.13	35.06	23.05	0.000	1.450
10	26.13	35.06	23.05	0.048	1.402
20	26.09	35.08	23.08	0.096	1.354
30	26.02	35.07	23.10	0.144	1.306
50	25.76	35.08	23.18	0.239	1.211
75	23.80	35.18	23.85	0.349	1.101
100	22.57	35.15	24.19	0.447	1.003
150	21.28	35.16	24.55	0.628	0.822
200	17.50	34.81	25.26	0.783	0.667
250	14.29	34.46	25.72	0.911	0.539
300	10.81	34.19	26.19	1.017	0.433
400	08.23	34.15	26.59	1.188	0.262
500	06.84	34.21	26.83	1.329	0.121
600	05.93	34.29	27.02	1.450	0.000

STATION 4

M/V Hugh M. Smith: Cruise 17, 22°28'N, 159°15'W,
September 7, 1952. Messenger time: 0744 GCT.
Weather: 02, cloud coverage 4. Wind: 080°, 19 kt.
Sea: 3-5 ft. Wire angle: 25°. Depth of water: 1800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.90	35.07	23.14		
22	25.88	35.07	23.14		
44	25.28	35.15	23.39		
87	24.28	35.14	23.69		
131	22.09	35.18	24.35		
174	20.81	35.16	24.68		
218	19.22	35.06	25.03		
262	16.61	34.70	25.39		
306	12.88	34.27	25.87		
350	10.58	34.14	26.20		
438	08.51	34.29	26.66		
525	06.30	34.02	26.76		
613	05.21	34.09	26.95		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.90	35.07	23.13	0.000	1.560
10	25.89	35.07	23.14	0.047	1.513
20	25.88	35.07	23.14	0.095	1.465
30	25.87	35.08	23.15	0.142	1.418
50	25.14	35.15	23.43	0.234	1.326
75	24.92	35.15	23.49	0.346	1.214
100	23.34	35.16	23.97	0.451	1.109
150	21.75	35.18	24.44	0.639	0.921
200	19.94	35.11	24.88	0.807	0.753
250	17.19	34.78	25.31	0.954	0.606
300	13.47	34.32	25.79	1.080	0.480
400	09.37	34.22	26.46	1.277	0.283
500	06.87	34.07	26.72	1.430	0.130
600	05.33	34.08	26.92	1.560	0.000

STATION 5

M/V Hugh M. Smith: Cruise 17, 23°14'N, 159°18'W, September 7, 1952. Messenger time: 1452 GCT. Weather: 03, cloud coverage 10. Wind: 090°, 22 kt. Sea: 3-5 ft. Wire angle: 12°.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.15	35.17			
24	25.16	35.21			
48	25.12	35.21			
95	23.23	35.13			
143	22.20	35.20			
190	21.32	35.25			
238	19.63	35.11			
286	16.56	34.72			
334	12.68	34.10			
381	10.64	34.14			
477	08.04	34.11			
573	06.06	34.05			
671	04.96	34.14			

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.15	35.17	23.44	0.000	1.615
10	25.15	35.19	23.46	0.044	1.571
20	25.16	35.21	23.47	0.089	1.526
30	25.16	35.21	23.47	0.133	1.482
50	25.12	35.21	23.48	0.222	1.393
75	25.12	35.21	23.48	0.333	1.282
100	23.06	35.14	24.04	0.437	1.178
150	22.09	35.22	24.37	0.625	0.990
200	21.12	35.25	24.67	0.800	0.815
250	19.09	35.05	25.05	0.958	0.657
300	15.22	34.51	25.56	1.096	0.519
400	10.07	34.14	26.28	1.313	0.302
500	07.52	34.09	26.65	1.479	0.136
600	05.67	34.07	26.88	1.615	0.000

STATION 6

M/V Hugh M. Smith: Cruise 17, 23°09'N, 158°26'W, September 7, 1952. Messenger time: 2153 GCT. Weather: 03, cloud coverage 4. Wind: 080°, 19 kt. Sea: 3-5 ft. Wire angle: 10°.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.38	35.18	23.38		
24	25.30	35.19	23.41		
48	25.28	35.21	23.44		
95	22.79	35.30	24.24		
143	21.35	35.22	24.58		
191	19.90	35.14	24.91		
239	17.10	34.77	25.33		
287	14.24	34.43	25.71		
335	11.82	34.23	26.04		
383	10.41	34.10	26.20		
479	08.24	34.04	26.50		
575	05.95	34.02	26.81		
671	04.98	34.06	26.96		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.38	35.18	23.38	0.000	1.543
10	25.32	35.18	23.40	0.045	1.498
20	25.30	35.19	23.41	0.090	1.453
30	25.30	35.19	23.41	0.135	1.408
50	25.28	35.21	23.43	0.225	1.318
75	23.02	35.30	24.17	0.328	1.215
100	22.71	35.30	24.26	0.421	1.122
150	21.25	35.22	24.61	0.599	0.944
200	19.46	35.10	24.99	0.759	0.784
250	16.41	34.68	25.42	0.901	0.642
300	13.60	34.37	25.80	1.024	0.519
400	10.03	34.08	26.24	1.232	0.311
500	07.67	34.03	26.58	1.402	0.141
600	05.66	34.03	26.85	1.543	0.000

STATION 7

M/V Hugh M. Smith: Cruise 17, 22°30'N, 158°20'W,
September 8, 1952. Messenger time: 0348 GCT.
Weather: 02, cloud coverage 3. Wind: 090°, 18 kt.
Sea: 3-5 ft. Wire angle: 15°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
01	25.40	35.19	23.38		
23	25.36	35.19	23.39		
46	24.40	35.14	23.65		
91	22.44	35.16	24.24		
137	21.16	35.23	24.64		
183	19.34	35.08	25.01		
228	16.78	34.74	25.38		
274	13.55	34.36	25.80		
320	12.04	34.26	26.03		
365	10.32	34.14	26.24		
457	08.03	34.12	26.60		
550	06.60	34.18	26.85		
646	06.02	34.29	27.01		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D 1000 - \Delta D$ (dyn. m)
00	25.40	35.19	23.38	0.000	1.474
10	25.38	35.19	23.38	0.045	1.429
20	25.36	35.19	23.39	0.090	1.384
30	25.33	35.19	23.40	0.135	1.339
50	24.01	35.14	23.76	0.222	1.252
75	23.02	35.15	24.06	0.322	1.152
100	22.25	35.17	24.29	0.417	1.057
150	20.60	35.20	24.77	0.590	0.884
200	18.92	35.03	25.08	0.745	0.729
250	14.88	34.51	25.63	0.879	0.595
300	12.72	34.31	25.93	0.994	0.480
400	09.34	34.12	26.39	1.187	0.287
500	07.25	34.15	26.73	1.343	0.131
600	06.28	34.22	26.92	1.474	0.000

STATION 8

M/V Hugh M. Smith: Cruise 17, 21°42'N, 158°20'W, September 8, 1952. Messenger time: first cast 1016 GCT, second cast 1042 GCT. Weather: 63, cloud coverage 7. Wind: 080°, 21 kt. Sea: 3-5 ft. Wire angle: first cast 15°, second cast 15°. Depth of water: 500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.82	35.11	23.19		
23	25.82	35.11	23.19		
45	25.44	35.18	23.36		
92	23.80	35.20	23.87		
137	21.78	35.32	24.54		
183	19.50	35.16	25.03		
229	15.86	34.64	25.52		
275	13.90	34.41	25.77		
321	11.44	34.24	26.12		
367	10.41	34.23	26.30		
460	08.07	34.18	26.54		
554	06.76	34.23	26.87		
648	05.85	34.32	27.06		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.82	35.11	23.19	0.000	1.500
10	25.82	35.11	23.19	0.047	1.453
20	25.82	35.11	23.19	0.094	1.406
30	25.60	35.16	23.29	0.140	1.360
50	25.43	35.18	23.36	0.232	1.268
75	24.33	35.20	23.71	0.341	1.159
100	23.70	35.20	23.90	0.445	1.055
150	20.68	35.27	24.80	0.626	0.874
200	19.30	35.14	25.06	0.781	0.719
250	14.80	34.51	25.65	0.915	0.585
300	12.60	34.30	25.94	1.029	0.471
400	09.40	34.21	26.45	1.219	0.281
500	07.45	34.20	26.74	1.372	0.128
600	06.28	34.27	26.96	1.500	0.000

STATION 9

M/V Hugh M. Smith: Cruise 17, 20°58'N, 158°14'W,
September 8, 1952. Messenger time: 2105 GCT.
Weather: 02, cloud coverage 3. Wind: 080°, 19 kt.
Sea: 3-5 ft. Wire angle: 35°. Depth of water: 1900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.47	35.10	23.29		
16	25.46	35.08	23.28		
34	25.39	35.11	23.33		
66	24.04	35.08	23.71		
99	22.64	35.21	24.22		
133	22.00	35.23	24.41		
165	21.23	35.19	24.59		
197	18.56	34.93	25.10		
230	15.50	34.52	25.51		
262	14.02	34.40	25.74		
328	11.02	34.17	26.15		
394	08.84	34.15	26.50		
458	07.58	34.19	26.72		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.47	35.10	23.29	0.000	1.473
10	25.47	35.09	23.28	0.046	1.427
20	25.46	35.09	23.28	0.092	1.381
30	25.42	35.10	23.30	0.138	1.335
50	25.36	35.11	23.33	0.230	1.243
75	23.24	35.15	23.99	0.336	1.137
100	22.63	35.21	24.21	0.432	1.041
150	21.50	35.21	24.53	0.613	0.860
200	18.35	34.90	25.12	0.772	0.701
250	14.60	34.44	25.64	0.905	0.568
300	12.22	34.24	25.97	1.019	0.454
400	08.72	34.15	26.51	1.204	0.269
500	06.91	34.20	26.82	1.350	0.123
600	05.91	34.25	26.99	1.473	0.000

STATION 10

M/V Hugh M. Smith: Cruise 17, 20°16'N, 158°15'W, September 9, 1952. Messenger time: 0318 GCT. Weather: 16, cloud coverage 8. Wind: 080°, 19 kt. Sea: 5-8 ft. Wire angle: 25°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	35.01	23.00		
24	26.20	35.04	23.02		
47	25.90	35.00	23.08		
95	25.06	35.03	23.37		
141	21.86	35.15	24.39		
188	19.32	34.96	24.93		
235	15.55	34.52	25.50		
282	12.34	34.19	25.92		
329	10.19	34.13	26.26		
377	08.90	34.12	26.46		
472	07.32	-	-		
566	06.14	34.23	26.95		
664	05.56	34.29	27.07		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.20	35.01	22.99	0.000	1.540
10	26.20	35.02	23.00	0.049	1.491
20	26.20	35.03	23.01	0.097	1.443
30	26.20	35.04	23.02	0.146	1.394
50	25.88	35.00	23.09	0.243	1.297
75	25.87	35.00	23.09	0.363	1.177
100	24.89	35.04	23.42	0.480	1.060
150	21.58	35.14	24.46	0.681	0.859
200	18.69	34.91	25.04	0.844	0.696
250	14.98	34.45	25.57	0.981	0.559
300	11.29	34.15	26.08	1.093	0.447
400	08.48	34.13	26.53	1.272	0.268
500	06.90	34.19	26.81	1.417	0.123
600	05.92	34.25	26.99	1.540	0.000

STATION 11

M/V Hugh M. Smith: Cruise 17, 19°26'N, 158°15'W,
September 9, 1952. Messenger time: 0940 GCT.
Weather: 02, cloud coverage 9. Wind: 150°, 6 kt.
Sea: 3-5 ft. Wire angle: 12°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.01	35.01	23.06		
24	26.02	35.04	23.08		
47	25.92	35.01	23.09		
92	24.23	35.08	23.65		
140	22.01	35.17	24.36		
187	19.66	35.09	24.94		
233	16.00	34.59	25.45		
280	11.95	34.21	26.01		
327	10.04	34.12	26.28		
374	08.53	34.10	26.51		
468	07.20	34.25	26.82		
562	06.42	34.34	27.00		
659	05.66	34.36	27.11		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.01	35.01	23.05	0.000	1.491
10	26.01	35.02	23.06	0.048	1.443
20	26.02	35.03	23.07	0.096	1.395
30	26.01	35.03	23.07	0.144	1.347
50	25.90	35.01	23.09	0.241	1.250
75	25.35	35.03	23.27	0.359	1.132
100	23.88	35.10	23.77	0.469	1.022
150	21.54	35.16	24.48	0.661	0.830
200	18.81	34.99	25.08	0.823	0.668
250	14.28	34.42	25.69	0.956	0.535
300	11.11	34.16	26.12	1.064	0.427
400	08.01	34.14	26.61	1.238	0.253
500	06.92	34.30	26.89	1.374	0.117
600	06.12	34.35	27.04	1.491	0.000

STATION 12

M/V Hugh M. Smith: Cruise 17, 18°52'N, 157°21'W,
September 9, 1952. Messenger time: 1850 GCT.
Weather: 02, cloud coverage 5. Wind: 110°, 18 kt.
Sea: 5-8 ft. Wire angle: 08°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
03	26.30	34.99	22.95		
27	25.58	35.07	23.24		
51	25.16	35.07	23.37		
98	22.10	35.20	24.36		
146	20.16	35.10	24.81		
194	17.60	34.78	25.22		
243	13.70	34.45	25.84		
291	11.08	34.19	26.15		
339	09.20	34.11	26.41		
387	07.83	34.16	26.66		
484	06.56	34.14	26.82		
582	05.73	34.20	26.98		
680	05.35	34.30	27.10		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.30	34.99	22.95	0.000	1.412
10	26.30	34.99	22.95	0.049	1.363
20	26.00	35.03	23.07	0.098	1.314
30	25.57	35.07	23.24	0.145	1.267
50	25.20	35.07	23.35	0.237	1.175
75	24.52	35.09	23.57	0.349	1.063
100	22.02	35.20	24.38	0.448	0.964
150	19.90	35.07	24.86	0.617	0.795
200	17.40	34.76	25.25	0.765	0.647
250	13.00	34.57	25.92	0.889	0.523
300	10.72	34.17	26.19	0.990	0.422
400	07.60	34.17	26.70	1.155	0.257
500	06.40	34.14	26.84	1.290	0.122
600	05.63	34.21	26.99	1.412	0.000

STATION 13

M/V Hugh M. Smith: Cruise 17, 19°29'N, 157°16'W, September 10, 1952. Messenger time: 0042 GCT. Weather: 02, cloud coverage 3. Wind: 050°, 11 kt. Sea: 5-8 ft. Wire angle: 15°. Depth of water: 2000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.78	35.25	23.62		
25	22.96	35.16	24.09		
49	21.96	35.17	24.38		
97	20.38	35.15	24.79		
145	18.41	34.91	25.12		
193	15.46	34.52	25.52		
242	12.69	34.24	25.89		
291	10.64	34.16	26.20		
340	09.42	34.07	26.34		
388	08.16	34.05	26.53		
485	06.75	34.14	26.80		
582	05.61	34.32	27.08		
680	05.10	34.40	27.21		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.78	35.25	23.61	0.000	1.291
10	24.20	35.20	23.75	0.042	1.249
20	23.22	35.17	24.01	0.083	1.208
30	22.70	35.16	24.16	0.121	1.170
50	21.88	35.17	24.40	0.194	1.097
75	21.00	35.16	24.63	0.281	1.010
100	20.24	35.14	24.82	0.362	0.929
150	18.19	34.88	25.15	0.513	0.778
200	15.11	34.47	25.55	0.647	0.644
250	12.40	34.23	25.93	0.763	0.528
300	10.43	34.14	26.22	0.863	0.428
400	07.97	34.05	26.55	1.034	0.257
500	06.53	34.18	26.85	1.176	0.115
600	05.50	34.34	27.11	1.291	0.000

STATION 14

M/V Hugh M. Smith: Cruise 17, 20°15'N, 157°22'W, September 10, 1952. Messenger time: 0705 GCT. Weather: 62, cloud coverage 10. Wind: 120°, 13 kt. Sea: 3-5 ft. Wire angle: 32°. Depth of water: 2100 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.51	35.22	23.68		
17	24.52	35.22	23.67		
35	23.34	35.13	23.95		
71	22.06	35.16	24.34		
108	20.68	35.15	24.71		
144	19.30	35.07	25.02		
181	16.75	34.70	25.36		
217	14.60	34.50	25.69		
253	12.76	34.31	25.93		
289	10.82	34.18	26.19		
363	08.92	34.13	26.47		
437	07.10	34.13	26.74		
511	06.08	34.23	26.96		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.51	35.22	23.67	0.000	1.314
10	24.51	35.22	23.67	0.042	1.272
20	24.52	35.22	23.67	0.085	1.229
30	23.98	35.16	23.78	0.127	1.187
50	22.75	35.14	24.13	0.206	1.108
75	22.00	35.16	24.35	0.299	1.015
100	21.14	35.16	24.59	0.386	0.928
150	19.00	35.03	25.06	0.545	0.769
200	15.67	34.60	25.53	0.682	0.632
250	12.99	34.33	25.89	0.799	0.515
300	10.53	34.17	26.23	0.900	0.414
400	07.83	34.12	26.62	1.067	0.247
500	06.23	34.21	26.92	1.202	0.112
600	05.45	34.34	27.12	1.314	0.000

STATION 15

M/V Hugh M. Smith: Cruise 17, 20°43'N, 157°26'W, September 10, 1952. Messenger time: 1247 GCT. Weather: 02, cloud coverage 9. Wind: 090°, 6 kt. Sea: 1-3 ft. Wire angle: 10°. Depth of water: 1500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.92	35.03	23.10		
24	25.86	35.06	23.14		
48	25.62	35.01	23.18		
95	23.41	35.10	23.91		
143	21.06	35.10	24.57		
192	19.18	34.99	24.99		
240	15.38	34.52	25.54		
288	13.04	34.29	25.85		
335	09.88	34.12	26.30		
383	08.91	34.14	26.48		
479	07.44	34.18	26.73		
575	06.32	34.23	26.92		
672	05.52	34.39	27.15		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.92	35.03	23.10	0.000	1.515
10	25.90	35.04	23.11	0.048	1.467
20	25.89	35.05	23.12	0.095	1.420
30	25.80	35.05	23.15	0.143	1.372
50	25.60	35.01	23.18	0.237	1.278
75	25.20	35.02	23.31	0.354	1.161
100	23.33	35.11	23.94	0.462	1.053
150	21.00	35.10	24.58	0.647	0.868
200	18.70	34.94	25.07	0.807	0.708
250	14.68	34.45	25.63	0.942	0.573
300	12.40	34.24	25.94	1.056	0.459
400	08.61	34.15	26.53	1.242	0.273
500	07.15	34.19	26.78	1.389	0.126
600	06.09	34.26	26.97	1.515	0.000

STATION 16

M/V Hugh M. Smith: Cruise 17, 21°48'N, 157°18'W,
September 10, 1952. Messenger time: 2118 GCT.
Weather: 02, cloud coverage 8. Wind: 080°, 16 kt.
Sea: 3-5 ft. Wire angle: 25°. Depth of water: 1900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.19	35.13	23.40		
23	25.13	35.09	23.39		
45	25.08	35.11	23.42		
91	22.72	35.16	24.16		
135	21.82	35.25	24.48		
181	19.92	35.16	24.92		
226	17.55	34.81	25.25		
271	14.52	34.44	25.66		
317	11.40	34.19	26.09		
362	09.46	34.11	26.37		
452	07.09	34.12	26.74		
542	05.95	34.22	26.96		
633	05.58	34.35	27.11		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.19	35.13	23.40	0.000	1.466
10	25.15	35.11	23.39	0.045	1.421
20	25.14	35.10	23.39	0.090	1.376
30	25.10	35.10	23.40	0.135	1.331
50	25.05	35.11	23.43	0.225	1.241
75	23.26	35.14	23.98	0.330	1.136
100	22.58	35.18	24.21	0.427	1.039
150	21.50	35.25	24.56	0.607	0.859
200	18.99	35.05	25.08	0.766	0.700
250	15.79	34.58	25.49	0.905	0.561
300	12.50	34.26	25.93	1.023	0.443
400	08.29	34.10	26.54	1.209	0.257
500	06.36	34.17	26.87	1.350	0.116
600	05.63	34.31	27.07	1.466	0.000

STATION 17

M/V Hugh M. Smith: Cruise 17, 22°26'N, 157°16'W, September 11, 1952. Messenger time: 0335 GCT. Weather: 03, cloud coverage 6. Wind: 100°, 22 kt. Sea: 5-8 ft. Wire angle: 15°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.30	35.22	23.44		
24	25.30	35.23	23.44		
48	24.64	35.45	23.81		
95	21.49	35.26	24.58		
143	20.08	35.22	24.93		
190	18.64	35.04	25.16		
237	16.01	34.66	25.50		
286	13.60	34.42	25.84		
333	11.36	34.20	26.11		
380	09.42	34.14	26.40		
476	07.29	34.13	26.72		
573	05.14	34.10	26.97		
669	04.62	34.22	27.12		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.30	35.22	23.43	0.000	1.426
10	25.30	35.22	23.43	0.045	1.381
20	25.30	35.23	23.44	0.089	1.337
30	25.30	35.28	23.48	0.134	1.292
50	24.46	35.45	23.86	0.219	1.207
75	22.74	35.24	24.21	0.316	1.110
100	21.37	35.26	24.60	0.405	1.021
150	20.00	35.21	24.94	0.567	0.859
200	18.55	35.02	25.16	0.715	0.711
250	15.32	34.59	25.60	0.849	0.577
300	12.93	34.35	25.92	0.965	0.461
400	08.99	34.14	26.46	1.155	0.271
500	06.62	34.12	26.79	1.304	0.122
600	04.95	34.13	27.01	1.426	0.000

STATION 18

M/V Hugh M. Smith: Cruise 17, 21°45'N, 156°20'W, September 11, 1952. Messenger time: 1238 GCT. Weather: 02, cloud coverage 4. Wind: 100°, 19 kt. Sea: 3-5 ft. Wire angle: 28°. Depth of water: 3000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.10	35.14	23.44		
21	25.12	35.14	23.43		
42	25.00	35.32	23.60		
84	22.61	35.22	24.23		
126	21.56	35.29	24.58		
170	19.94	35.22	24.96		
212	17.36	34.79	25.28		
256	14.88	34.50	25.63		
298	11.74	34.20	26.04		
341	10.52	34.16	26.23		
427	08.08	34.08	26.56		
514	07.02	34.21	26.82		
601	05.83	34.22	26.98		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.10	35.14	23.43	0.000	1.447
10	25.11	35.14	23.43	0.045	1.402
20	25.12	35.14	23.43	0.089	1.358
30	25.07	35.20	23.49	0.134	1.313
50	24.92	35.35	23.65	0.221	1.226
75	23.01	35.23	24.12	0.322	1.125
100	21.99	35.27	24.44	0.414	1.033
150	20.96	35.28	24.73	0.584	0.863
200	18.75	35.03	25.12	0.739	0.708
250	15.34	34.55	25.56	0.874	0.573
300	11.62	34.20	26.05	0.987	0.460
400	08.68	34.09	26.47	1.170	0.277
500	07.23	34.19	26.77	1.320	0.127
600	05.84	34.22	26.97	1.447	0.000

STATION 19

M/V Hugh M. Smith: Cruise 17, 21°17'N, 156°16'W, September 11, 1952. Messenger time: 1807 GCT. Weather: 02, cloud coverage 6. Wind: 090°, 21 kt. Sea: 3-5 ft. Wire angle: 08°. Depth of water 600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.59	35.09	23.25		
24	25.58	35.10	23.26		
47	24.08	35.22	23.80		
95	22.02	35.28	24.44		
143	20.84	35.29	24.77		
190	18.97	35.04	25.08		
236	16.10	34.62	25.45		
285	12.58	34.28	25.94		
332	10.62	34.18	26.22		
381	09.12	-	-		
476	06.94	34.15	26.78		
572	06.02	34.27	27.00		
667	05.64	34.37	27.12		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.59	35.09	23.24	0.000	1.428
10	25.59	35.09	23.24	0.046	1.382
20	25.58	35.10	23.26	0.093	1.335
30	25.54	35.10	23.27	0.139	1.289
50	23.90	35.23	23.86	0.226	1.202
75	22.60	35.27	24.27	0.323	1.105
100	21.80	35.29	24.51	0.412	1.016
150	20.66	35.28	24.81	0.579	0.849
200	18.40	34.95	25.15	0.731	0.697
250	15.36	34.54	25.55	0.866	0.562
300	11.94	34.23	26.02	0.980	0.448
400	08.61	34.10	26.49	1.165	0.263
500	06.62	34.19	26.85	1.309	0.119
600	05.88	34.31	27.04	1.428	0.000

STATION 20

M/V Hugh M. Smith: Cruise 17, 21°02'N, 155°37'W, September 12, 1952. Messenger time: 0006 GCT. Weather: 02, cloud coverage 2. Wind: 110°, 13 kt. Sea: 1-3 ft. Wire angle: 25°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.21	35.28	23.51		
23	25.06	35.31	23.58		
46	24.96	35.30	23.60		
91	22.33	35.22	24.31		
136	21.19	35.28	24.67		
181	19.98	35.22	24.95		
226	17.68	34.84	25.25		
272	14.21	34.42	25.71		
317	11.71	34.22	26.06		
363	09.24	34.13	26.42		
455	07.32	34.06	26.65		
546	06.21	34.20	26.92		
639	05.60	34.29	27.06		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.21	35.28	23.50	0.000	1.456
10	25.12	35.31	23.55	0.044	1.412
20	25.06	35.31	23.57	0.087	1.369
30	25.04	35.30	23.57	0.130	1.326
50	24.97	35.30	23.59	0.217	1.239
75	23.40	35.22	24.00	0.320	1.136
100	22.11	35.23	24.38	0.414	1.042
150	20.62	35.27	24.82	0.584	0.872
200	19.39	35.14	25.04	0.739	0.717
250	16.42	34.69	25.43	0.879	0.577
300	12.72	34.28	25.91	1.000	0.456
400	08.34	34.08	26.52	1.188	0.268
500	06.70	34.14	26.80	1.334	0.122
600	05.80	34.26	27.01	1.456	0.000

STATION 21

M/V Hugh M. Smith: Cruise 17, 20°28'N, 155°37'W, September 12, 1952. Messenger time: 0505 GCT. Weather: 02, cloud coverage 3. Wind: 090°, 20 kt. Sea: 3-5 ft. Wire angle: 12°. Depth of water: 1500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.51	35.05	23.24		
23	25.51	35.06	23.25		
47	25.02	35.26	23.55		
94	23.50	35.22	23.98		
142	21.34	35.26	24.62		
189	19.50	35.11	24.99		
237	17.11	34.76	25.32		
284	13.22	34.31	25.83		
332	10.56	34.17	26.23		
380	09.08	34.13	26.44		
476	07.18	34.18	26.77		
572	05.49	34.21	27.01		
668	05.26	34.34	27.14		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.51	35.05	23.24	0.000	1.484
10	25.51	35.05	23.24	0.046	1.438
20	25.51	35.06	23.25	0.093	1.391
30	25.46	35.08	23.28	0.139	1.345
50	25.00	35.26	23.55	0.229	1.255
75	24.81	35.26	23.61	0.337	1.147
100	23.44	35.22	23.99	0.441	1.043
150	21.04	35.25	24.69	0.623	0.861
200	19.10	35.06	25.06	0.780	0.704
250	16.10	34.64	25.46	0.920	0.564
300	12.25	34.25	25.97	1.037	0.447
400	08.62	34.14	26.52	1.222	0.262
500	06.62	34.19	26.85	1.366	0.118
600	05.38	34.25	27.05	1.484	0.000

STATION 22

M/V Hugh M. Smith: Cruise 17, 20°12'N, 156°19'W, September 12, 1952. Messenger time: 1113 GCT. Weather: 02, cloud coverage 2. Wind: 090°, 22 kt. Sea: 3-5 ft. Wire angle: 15°. Depth of water: 800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.70	35.05	23.18		
24	25.70	35.01	23.15		
48	25.64	35.00	23.17		
97	22.32	35.12	24.24		
145	20.61	35.12	24.71		
193	18.74	34.98	25.09		
241	15.06	34.50	25.59		
289	12.96	34.32	25.90		
337	10.40	34.18	26.26		
385	09.06	34.17	26.48		
482	07.04	34.22	26.82		
578	06.12	34.26	26.98		
674	05.53	34.36	27.13		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.70	35.05	23.18	0.000	1.462
10	25.70	35.03	23.17	0.047	1.415
20	25.70	35.01	23.15	0.094	1.368
30	25.68	35.00	23.15	0.142	1.320
50	25.63	35.00	23.16	0.236	1.226
75	23.41	35.11	23.91	0.346	1.116
100	22.21	35.12	24.26	0.442	1.020
150	20.48	35.12	24.74	0.617	0.845
200	18.45	34.94	25.13	0.771	0.691
250	14.58	34.45	25.65	0.904	0.558
300	12.41	34.29	25.97	1.017	0.445
400	08.62	34.18	26.55	1.200	0.262
500	06.84	34.23	26.85	1.342	0.120
600	05.95	34.29	27.01	1.462	0.000

STATION 23

M/V Hugh M. Smith: Cruise 17, 19°30'N, 156°15'W,
September 12, 1952. Messenger time: 1732 GCT.
Weather: 01, cloud coverage 2. Wind: 030°, 13 kt.
Sea: <1 ft. Wire angle: 17°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.31	34.98	22.94		
21	26.06	34.97	23.01		
41	25.89	34.96	23.06		
83	25.16	34.98	23.30		
125	22.10	35.11	24.29		
166	20.58	35.18	24.76		
208	18.17	34.86	25.14		
249	14.28	34.39	25.68		
291	11.41	34.13	26.04		
332	09.72	34.12	26.33		
417	08.15	34.15	26.60		
501	06.66	34.19	26.85		
587	05.98	34.30	27.02		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.31	34.98	22.94	0.000	1.515
10	26.20	34.98	22.97	0.049	1.466
20	26.08	34.97	23.00	0.098	1.417
30	25.99	34.96	23.02	0.147	1.368
50	25.83	34.96	23.07	0.243	1.272
75	25.38	34.97	23.22	0.362	1.153
100	24.97	34.98	23.35	0.478	1.037
150	21.00	35.17	24.64	0.677	0.838
200	18.65	34.93	25.07	0.835	0.680
250	14.20	34.38	25.68	0.968	0.547
300	11.01	34.13	26.11	1.077	0.438
400	08.43	34.14	26.55	1.254	0.261
500	06.68	34.19	26.84	1.396	0.119
600	05.92	34.32	27.04	1.515	0.000

STATION 24

M/V Hugh M. Smith: Cruise 17, 18°46'N, 156°14'W,
September 12, 1952. Messenger time: 2335 GCT.
Weather: 02, cloud coverage 1. Wind: 100°, 15 kt.
Sea: 1-3 ft. Wire angle: 25°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.98	34.99	23.05		
21	25.86	34.98	23.08		
42	25.78	34.98	23.11		
85	23.12	35.07	23.97		
129	21.20	35.16	24.58		
171	19.20	34.99	24.98		
214	17.32	34.76	25.27		
257	14.80	34.51	25.66		
299	12.04	34.20	25.98		
341	09.77	34.14	26.34		
428	07.83	34.18	26.67		
514	06.41	34.22	26.91		
599	05.74	34.31	27.06		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.98	34.99	23.05	0.000	1.464
10	25.95	34.99	23.06	0.048	1.416
20	25.87	34.98	23.08	0.096	1.368
30	25.82	34.98	23.09	0.144	1.320
50	25.67	34.98	23.14	0.240	1.224
75	24.30	35.00	23.57	0.354	1.110
100	22.05	35.14	24.32	0.454	1.010
150	19.92	35.07	24.85	0.624	0.840
200	18.19	34.86	25.13	0.775	0.689
250	15.45	34.57	25.55	0.911	0.553
300	11.98	34.20	25.99	1.026	0.438
400	08.43	34.16	26.57	1.208	0.256
500	06.60	34.22	26.88	1.348	0.116
600	05.72	34.32	27.07	1.464	0.000

STATION 25

M/V Hugh M. Smith: Cruise 17, 18°10'N, 155°33'W,
September 13, 1952. Messenger time: 0742 GCT.
Weather: 03, cloud coverage 9. Wind: 080°, 21 kt.
Sea: 3-5 ft. Wire angle: 35°.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.85	34.95	23.06		
21	25.86	34.95	23.06		
41	25.77	34.97	23.10		
81	23.65	35.20	23.92		
81	23.85	35.20	23.86		
122	21.28	35.21	24.60		
164	20.40	35.26	24.87		
205	18.70	34.96	25.08		
245	14.94	34.42	25.56		
287	12.04	34.16	25.95		
328	10.14	34.16	26.29		
410	07.91	34.14	26.63		
492	06.64	34.22	26.87		
574	05.98	34.29	27.02		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.85	34.95	23.06	0.000	1.458
10	25.85	34.95	23.06	0.048	1.410
20	25.86	34.95	23.06	0.096	1.362
30	25.80	34.96	23.08	0.144	1.314
50	25.71	34.98	23.12	0.240	1.218
75	24.25	35.18	23.72	0.353	1.105
100	22.42	35.20	24.27	0.451	1.007
150	20.70	35.25	24.78	0.625	0.833
200	19.00	35.01	25.04	0.780	0.678
250	14.40	34.36	25.62	0.916	0.542
300	11.27	34.15	26.08	1.027	0.431
400	08.14	34.14	26.59	1.203	0.255
500	06.58	34.23	26.89	1.341	0.117
600	05.82	34.31	27.05	1.458	0.000

STATION 26

M/V Hugh M. Smith: Cruise 17, 18°49'N, 155°32'W, September 13, 1952. Messenger time: 1340 GCT. Weather: 02, cloud coverage 7. Wind: 040°, 18 kt. Sea: 3-5 ft. Wire angle: 20°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.31	35.05	23.30		
22	25.32	35.04	23.29		
45	24.94	35.08	23.44		
90	23.14	35.23	24.09		
135	20.93	35.24	24.71		
180	19.82	35.26	25.03		
226	17.36	34.79	25.28		
271	13.58	34.34	25.78		
315	10.95	34.14	26.14		
363	09.46	34.18	26.42		
454	07.12	34.13	26.74		
547	06.16	34.26	26.97		
639	05.68	34.38	27.12		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.31	35.05	23.30	0.000	1.447
10	25.31	35.05	23.30	0.046	1.401
20	25.32	35.04	23.29	0.092	1.355
30	25.30	35.04	23.30	0.138	1.309
50	24.67	35.11	23.54	0.227	1.220
75	23.53	35.21	23.95	0.332	1.115
100	22.90	35.24	24.16	0.429	1.018
150	20.38	35.26	24.87	0.603	0.844
200	19.54	35.24	25.08	0.755	0.692
250	15.92	34.61	25.48	0.894	0.553
300	11.65	34.17	26.03	1.010	0.437
400	08.33	34.16	26.58	1.189	0.258
500	06.59	34.18	26.85	1.329	0.118
600	05.83	34.34	27.07	1.447	0.000

STATION 27

M/V Hugh M. Smith: Cruise 17, 18°46'N, 154°39'W,
September 13, 1952. Messenger time: 2128 GCT.
Weather: 02, cloud coverage 6. Wind: 050°, 14 kt.
Sea: 3-5 ft. Wire angle: 25°. Depth of water: 2900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.29	35.28	23.48		
21	25.18	35.26	23.50		
42	24.98	35.26	23.56		
85	22.10	35.27	24.41		
128	20.54	35.25	24.83		
171	19.62	35.19	25.02		
215	16.72	34.69	25.36		
258	12.91	34.24	25.84		
301	10.52	34.13	26.20		
345	09.00	34.09	26.43		
431	07.70	34.18	26.69		
520	06.30	34.23	26.93		
607	05.88	34.35	27.08		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.29	35.28	23.48	0.000	1.376
10	25.24	35.27	23.49	0.044	1.332
20	25.19	35.26	23.50	0.088	1.288
30	25.08	35.26	23.53	0.132	1.244
50	24.81	35.27	23.62	0.219	1.157
75	22.65	35.27	24.25	0.319	1.057
100	21.52	35.27	24.57	0.408	0.968
150	20.06	35.22	24.93	0.570	0.806
200	18.12	34.93	25.20	0.718	0.658
250	13.42	34.29	25.77	0.846	0.530
300	10.59	34.13	26.19	0.951	0.425
400	08.16	34.14	26.59	1.122	0.254
500	06.54	34.22	26.88	1.260	0.116
600	05.90	34.34	27.06	1.376	0.000

STATION 28

M/V Hugh M. Smith: Cruise 17, 19°30'N, 154°26'W, September 14, 1952. Messenger time: 0403 GCT. Weather: 02, cloud coverage 7. Wind: 090°, 13 kt. Sea: 3-5 ft. Wire angle: not recorded.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.40	35.29	23.46		
22	25.18	35.30	23.53		
45	24.86	35.27	23.61		
91	22.04	35.26	24.42		
136	20.50	35.28	24.86		
181	18.32	34.95	25.17		
228	16.09	34.62	25.45		
273	12.25	34.24	25.97		
318	10.10	34.12	26.27		
364	08.81	34.09	26.45		
455	07.28	34.19	26.76		
546	06.05	34.24	26.97		
639	05.64	34.35	27.10		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.40	35.29	23.45	0.000	1.384
10	25.39	35.30	23.46	0.044	1.340
20	25.21	35.30	23.52	0.088	1.296
30	25.08	35.29	23.55	0.132	1.252
50	24.70	35.26	23.64	0.218	1.166
75	22.80	35.26	24.20	0.319	1.065
100	21.52	35.27	24.57	0.408	0.976
150	20.08	35.25	24.95	0.570	0.814
200	17.25	34.78	25.30	0.712	0.669
250	14.73	34.47	25.64	0.844	0.540
300	10.79	34.16	26.17	0.953	0.431
400	08.23	34.12	26.56	1.126	0.258
500	06.60	34.21	26.87	1.266	0.118
600	05.77	34.30	27.05	1.384	0.000

STATION 29

M/V Hugh M. Smith: Cruise 17, 20°13'N, 154°28'W, September 14, 1952. Messenger time: 1036 GCT. Weather: 02, cloud coverage 7. Wind: 090°, 8 kt. Sea: 1-3 ft. Wire angle: 08°.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.21	35.07	23.35		
24	25.23	35.09	23.36		
48	24.68	35.17	23.58		
95	21.77	35.20	24.45		
144	20.48	35.25	24.84		
192	18.65	34.98	25.11		
240	15.51	34.53	25.52		
288	12.34	34.24	25.95		
337	09.84	34.10	26.30		
384	08.60	34.04	26.45		
482	06.56	34.08	26.78		
579	05.85	34.25	27.00		
677	05.48	34.37	27.14		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.21	35.07	23.35	0.000	1.430
10	25.22	35.08	23.35	0.045	1.385
20	25.23	35.09	23.36	0.091	1.339
30	25.23	35.10	23.36	0.136	1.294
50	24.55	35.17	23.62	0.224	1.206
75	23.38	35.19	23.98	0.328	1.102
100	21.52	35.20	24.52	0.420	1.010
150	20.20	35.23	24.90	0.585	0.845
200	18.36	34.94	25.15	0.735	0.695
250	14.78	34.45	25.61	0.868	0.562
300	11.79	34.21	26.03	0.981	0.449
400	08.25	34.04	26.50	1.164	0.266
500	06.37	34.10	26.81	1.310	0.120
600	05.73	34.30	27.05	1.430	0.000

STATION 30

M/V Hugh M. Smith: Cruise 17, 20°54'N, 154°30'W,
September 14, 1952. Messenger time: 1719 GCT.
Weather: 02, cloud coverage 8. Wind: 080°, 16 kt.
Sea: 3-5 ft. Wire angle: 10°. Depth of water: 2900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.27	35.16	23.40		
23	25.26	35.16	23.40		
46	25.17	35.15	23.42		
92	22.04	35.30	24.45		
140	20.74	35.26	24.78		
187	19.46	35.16	25.04		
233	17.40	34.83	25.31		
279	13.24	34.28	25.81		
326	10.90	34.13	26.14		
373	09.30	34.10	26.38		
467	07.16	34.11	26.72		
562	06.16	34.26	26.97		
659	05.64	34.34	27.10		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.27	35.16	23.40	0.000	1.447
10	25.27	35.16	23.40	0.045	1.402
20	25.26	35.16	23.40	0.090	1.357
30	25.24	35.15	23.40	0.135	1.312
50	25.13	35.15	23.43	0.225	1.222
75	23.35	35.25	24.04	0.330	1.117
100	21.83	35.30	24.51	0.422	1.025
150	20.45	35.24	24.84	0.588	0.859
200	19.09	35.11	25.10	0.740	0.707
250	15.80	34.59	25.49	0.878	0.569
300	11.95	34.19	25.98	0.995	0.452
400	08.48	34.10	26.51	1.180	0.267
500	06.74	34.16	26.81	1.325	0.122
600	05.90	34.29	27.02	1.447	0.000

STATION 31

M/V Hugh M. Smith: Cruise 17, 21°44'N, 155°34'W,
September 15, 1952. Messenger time: 0328 GCT.
Weather: 02, cloud coverage 6. Wind: 080°, 14 kt.
Sea: 3-5 ft. Wire angle: 15°.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.09	35.33	23.58		
23	25.00	35.35	23.62		
46	24.95	35.35	23.64		
92	22.22	35.25	24.36		
140	21.12	35.33	24.73		
187	20.60	35.34	24.88		
235	19.23	35.11	25.06		
282	14.70	34.43	25.62		
329	11.68	34.17	26.02		
377	09.74	34.12	26.33		
472	07.60	34.15	26.68		
567	05.96	34.16	26.92		
663	05.36	34.26	27.07		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.09	35.33	23.58	0.000	1.494
10	25.05	35.34	23.60	0.043	1.451
20	25.01	35.35	23.62	0.086	1.408
30	24.99	35.35	23.62	0.129	1.365
50	24.93	35.35	23.64	0.214	1.280
75	22.72	35.26	24.23	0.315	1.179
100	22.01	35.25	24.42	0.406	1.088
150	21.05	35.34	24.75	0.576	0.918
200	20.52	35.33	24.89	0.735	0.759
250	18.35	34.98	25.18	0.886	0.608
300	13.42	34.30	25.78	1.015	0.479
400	09.22	34.12	26.41	1.215	0.279
500	07.02	34.15	26.76	1.368	0.126
600	05.68	34.19	26.97	1.494	0.000

STATION 1

M/V Hugh M. Smith: Cruise 20, 23°44'N, 158°02'W, March 9, 1953. Messenger time: first cast 0808 GCT, second cast 1032 GCT. Weather: 02, cloud coverage 2. Wind: 100°, 1 kt. Sea: < 1 ft. Wire angle: first cast 16°, second cast 12°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
04	22.94	35.12	24.06		
14	22.76	35.20	24.17		
27	22.58	35.25	24.26		
51	22.47	35.33	24.36		
97	20.38	35.16	24.80		
193	14.24	34.40	25.69		
284	09.82	34.08	26.28		
382	07.57	34.06	26.62		
477	05.99	34.07	26.84		
577	05.12	34.15	27.01		
796	04.31	34.41	27.31		
988	03.85	34.47	27.40		
1186	03.36	34.44	27.42		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	22.96	35.12	24.05	0.000	1.591
10	22.84	35.18	24.13	0.038	1.553
20	22.67	35.22	24.21	0.076	1.515
30	22.53	35.26	24.28	0.113	1.478
50	22.46	35.33	24.35	0.185	1.406
75	22.45	35.29	24.33	0.276	1.315
100	20.12	35.12	24.84	0.361	1.230
150	16.38	34.67	25.42	0.505	1.086
200	14.17	34.39	25.69	0.629	0.962
250	11.42	34.16	26.06	0.738	0.853
300	09.38	34.07	26.34	0.832	0.759
400	07.17	34.06	26.67	0.991	0.600
500	05.73	34.08	26.88	1.124	0.467
600	04.96	34.18	27.05	1.241	0.350
700	04.54	34.33	27.21	1.341	0.250
800	04.28	34.42	27.31	1.430	0.161
1000	03.81	34.47	27.40	1.591	0.000

STATION 2

M/V Hugh M. Smith: Cruise 20, 24°46'N, 158°02'W, March 9, 1953. Messenger time: first cast 2020 GCT, second cast 2053 GCT. Weather: 03, cloud coverage 2. Wind: 090°, 18 kt. Sea: 3-5 ft. Wire angle: first cast 40°, second cast 53°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	22.80	35.26	24.21		
08	22.72	35.27	24.23		
23	22.74	35.23	24.20		
45	22.60	35.43	24.39		
87	21.90	35.30	24.49		
171	18.54	34.96	25.12		
254	12.82	34.24	25.86		
332	09.74	-	-		
335	09.61	34.08	26.32		
405	08.44	34.07	26.50		
554	06.37	34.12	26.83		
717	04.84	34.11	27.01		
894	03.93	34.32	27.27		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	22.80	35.26	24.20	0.000	1.764
10	22.71	35.27	24.24	0.037	1.727
20	22.72	35.23	24.20	0.074	1.690
30	22.70	35.26	24.23	0.111	1.653
50	22.47	35.42	24.42	0.184	1.580
75	22.06	35.36	24.49	0.271	1.493
100	21.68	35.27	24.53	0.358	1.406
150	18.97	35.01	25.05	0.518	1.246
200	16.98	34.76	25.35	0.660	1.104
250	14.28	34.41	25.69	0.787	0.977
300	10.74	34.11	26.14	0.895	0.869
400	08.50	34.07	26.48	1.073	0.691
500	07.06	34.12	26.73	1.223	0.541
600	05.84	34.11	26.89	1.355	0.409
700	04.98	34.10	26.98	1.475	0.289
800	04.31	34.21	27.14	1.583	0.181
1000	03.73	34.40	27.35	1.764	0.000

STATION 3

M/V Hugh M. Smith: Cruise 20, 25°54'N, 157°59'W, March 10, 1953. Messenger time: 0716 GCT. Weather: 00, cloud coverage not recorded. Wind: 090°, 30 kt. Sea: 8-12 ft. Wire angle: 20°. Depth of water: 2100 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	22.00	35.36	24.52		
09	21.90	35.22	24.43		
28	21.36	35.31	24.65		
56	20.92	35.38	24.82		
110	19.52	35.17	25.03		
220	15.49	34.52	25.51		
331	11.80	-	-		
436	09.27	34.01	26.32		
547	07.14	33.98	26.62		
653	05.26	34.09	26.95		
871	04.04	34.28	27.23		
1083	03.53	34.30	27.30		
1287	03.16	34.40	27.41		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	21.95	35.36	24.52	0.000	1.795
10	21.88	35.22	24.43	0.035	1.760
20	21.76	35.27	24.50	0.069	1.726
30	21.30	35.32	24.67	0.103	1.692
50	20.99	35.37	24.79	0.168	1.627
75	20.60	35.37	24.90	0.246	1.549
100	19.82	35.23	25.00	0.322	1.473
150	18.30	34.95	25.17	0.468	1.327
200	16.64	34.65	25.34	0.607	1.188
250	13.92	34.31	25.69	0.734	1.061
300	12.60	34.18	25.85	0.849	0.946
400	10.10	34.04	26.20	1.055	0.740
500	08.03	33.99	26.49	1.232	0.563
600	06.06	34.02	26.79	1.380	0.415
700	04.90	34.15	27.03	1.503	0.292
800	04.36	34.24	27.16	1.607	0.188
1000	03.70	34.29	27.27	1.795	0.000

STATION 4

M/V Hugh M. Smith: Cruise 20, 27°00'N, 158°04'W, March 10, 1953. Messenger time: first cast 1817 GCT, second cast 1854 GCT, third cast 1930 GCT. Weather: 61, cloud coverage 10. Wind: 100°, 21 kt. Sea: 8-12 ft. Wire angle: first cast 35°, second cast 40°, third cast not recorded. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	20.60	35.01	24.63		
08	20.60	34.97	24.60		
23	20.60	35.07	24.67		
46	20.58	35.25	24.81		
92	19.68	35.05	24.90		
185	14.98	34.45	25.57		
278	12.17	34.25	26.00		
366	09.97	34.07	26.25		
462	08.14	33.98	26.47		
550	05.96	33.93	26.73		
778	04.31	34.04	27.01		
966	03.66	34.29	27.28		
1148	03.22	34.38	27.39		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	20.58	35.00	24.62	0.000	1.755
10	20.60	34.97	24.60	0.033	1.722
20	20.60	35.04	24.65	0.067	1.688
30	20.59	35.13	24.72	0.099	1.656
50	20.58	35.24	24.81	0.164	1.591
75	20.52	35.16	24.76	0.243	1.512
100	19.62	35.04	24.91	0.322	1.432
150	16.40	34.61	25.37	0.467	1.288
200	13.97	34.38	25.73	0.592	1.163
250	12.30	34.26	25.98	0.703	1.052
300	11.60	34.18	26.04	0.807	0.948
400	09.37	34.02	26.31	1.001	0.754
500	07.13	33.94	26.59	1.168	0.587
600	05.44	33.93	26.80	1.312	0.443
700	04.70	33.98	26.92	1.439	0.316
800	04.21	34.06	27.04	1.556	0.199
1000	03.62	34.30	27.29	1.755	0.000

STATION 5

M/V Hugh M. Smith: Cruise 20, 28°04'N, 158°02'W, March 11, 1953. Messenger time: first cast 0700 GCT, second cast 1731 GCT. Weather: 00, cloud coverage 10. Wind: 090°, 21 kt. Sea: 8-12 ft. Wire angle: first cast 23°, second cast 33°. Depth of water: 2800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	19.70	35.09	24.93		
13	19.70	35.09	24.93		
31	19.70	35.10	24.93		
65	19.52	35.01	24.91		
131	18.73	34.92	25.04		
263	12.49	34.17	25.87		
370	09.61	34.08	26.32		
502	06.96	34.01	26.67		
625	05.14	33.97	26.86		
759	04.24	34.15	27.11		
1020	03.48	34.34	27.33		
1287	02.96	34.46	27.48		
1560	02.47	34.51	27.56		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	19.68	35.09	24.93	0.000	1.707
10	19.70	35.09	24.92	0.030	1.677
20	19.69	35.09	24.93	0.061	1.646
30	19.69	35.10	24.93	0.091	1.616
50	19.62	35.05	24.91	0.152	1.555
75	19.50	34.99	24.90	0.229	1.478
100	19.57	34.96	24.86	0.307	1.400
150	17.95	34.84	25.18	0.456	1.251
200	15.06	34.45	25.55	0.590	1.117
250	12.84	34.20	25.82	0.708	0.999
300	11.51	34.13	26.02	0.816	0.891
400	08.97	34.07	26.41	1.004	0.703
500	07.00	34.01	26.66	1.162	0.545
600	05.42	33.97	26.83	1.300	0.407
700	04.52	34.07	27.01	1.420	0.287
800	04.06	34.20	27.16	1.525	0.182
1000	03.52	34.33	27.32	1.707	0.000

STATION 6

M/V Hugh M. Smith: Cruise 20, 29°10'N, 158°06'W, March 11, 1953. Messenger time: 1833 GCT. Weather: 01, cloud coverage 3. Wind: 070°, 20 kt. Sea: 8-12 ft. Wire angle: 28°. Depth of water: 3000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	18.80	34.94	25.03		
09	18.88	34.80	24.92		
26	18.89	34.97	25.04		
53	18.88	35.01	25.08		
105	18.05	34.83	25.15		
212	13.76	34.45	25.83		
319	11.40	34.26	26.14		
419	09.42	34.16	26.41		
526	07.31	33.97	26.59		
629	05.47	33.94	26.80		
841	04.24	34.25	27.19		
1050	03.55	34.37	27.35		
1253	03.14	34.45	27.45		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	18.85	34.94	25.03	0.000	1.695
10	18.86	34.80	24.92	0.030	1.665
20	18.87	34.92	25.01	0.060	1.635
30	18.88	34.98	25.05	0.089	1.606
50	18.88	35.01	25.07	0.148	1.547
75	18.88	34.96	25.04	0.221	1.474
100	18.33	34.88	25.11	0.294	1.401
150	16.49	34.64	25.37	0.433	1.262
200	14.01	34.46	25.78	0.556	1.139
250	12.72	34.37	25.97	0.665	1.030
300	11.79	34.29	26.09	0.767	0.928
400	09.81	34.18	26.36	0.955	0.740
500	07.83	34.02	26.55	1.121	0.574
600	05.84	33.93	26.74	1.269	0.426
700	04.97	34.04	26.94	1.398	0.297
800	04.42	34.20	27.12	1.509	0.186
1000	03.70	34.35	27.32	1.695	0.000

STATION 7

M/V Hugh M. Smith: Cruise 20, 29°06'N, 155°02'W, March 13, 1953. Messenger time: 0008 GCT. Weather: 03, cloud coverage 7. Wind: 120°, 14 kt. Sea: 3-5 ft. Wire angle: 18°. Depth of water: 3100 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	19.60	35.14	24.98		
09	19.81	35.15	24.94		
24	19.47	35.13	25.02		
52	19.45	35.14	25.03		
104	19.44	35.14	25.03		
211	15.10	34.51	25.59		
317	12.02	34.27	26.04		
426	09.62	34.15	26.37		
532	07.61	34.02	26.58		
638	05.84	34.02	26.82		
844	04.28	34.27	27.20		
1051	03.58	34.42	27.39		
1250	03.16	34.47	27.47		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	19.65	35.14	24.97	0.000	1.756
10	19.82	35.15	24.94	0.030	1.726
20	19.53	35.13	25.00	0.060	1.696
30	19.47	35.13	25.01	0.090	1.666
50	19.45	35.14	25.03	0.149	1.607
75	19.45	35.14	25.03	0.223	1.533
100	19.45	35.14	25.03	0.297	1.459
150	19.10	35.10	25.09	0.445	1.311
200	16.50	34.65	25.38	0.585	1.171
250	13.66	34.39	25.80	0.708	1.048
300	12.40	34.29	25.98	0.817	0.939
400	10.18	34.18	26.30	1.013	0.743
500	08.24	34.05	26.51	1.185	0.571
600	06.38	34.01	26.74	1.335	0.421
700	05.20	34.08	26.94	1.465	0.291
800	04.48	34.22	27.13	1.575	0.181
1000	03.67	34.41	27.37	1.756	0.000

STATION 8

M/V Hugh M. Smith: Cruise 20, 28°03'N, 155°02'W, March 13, 1953. Messenger time: 1013 GCT. Weather: 00, cloud coverage not recorded. Wind: 090°, 13 kt. Sea: 5-8 ft. Wire angle: 20°. Depth of water: 3200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	20.40	35.18	24.80		
09	20.68	35.19	24.74		
28	20.68	35.20	24.75		
57	20.65	35.20	24.76		
114	19.37	35.07	25.00		
228	13.56	34.27	25.73		
327	10.57	34.11	26.18		
432	08.64	34.00	26.41		
542	06.54	34.03	26.74		
627	05.22	34.04	26.91		
833	04.18	34.11	27.08		
1014	03.54	34.17	27.19		
1032	-	-	-		
1180	03.18	34.25	27.29		
1224	-	-	-		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	20.44	35.18	24.80	0.000	1.753
10	20.68	35.19	24.74	0.032	1.721
20	20.68	35.20	24.75	0.064	1.689
30	20.67	35.20	24.75	0.096	1.657
50	20.64	35.20	24.76	0.160	1.593
75	20.63	35.19	24.75	0.241	1.512
100	19.39	35.07	24.99	0.319	1.434
150	18.57	34.91	25.08	0.467	1.286
200	14.88	34.41	25.56	0.603	1.150
250	12.77	34.21	25.84	0.721	1.030
300	11.17	34.13	26.09	0.826	0.927
400	09.21	34.03	26.35	1.015	0.738
500	07.40	34.00	26.60	1.180	0.573
600	05.59	34.04	26.87	1.320	0.433
700	04.70	34.07	26.99	1.441	0.312
800	04.27	34.11	27.07	1.548	0.205
1000	03.58	34.16	27.18	1.753	0.000

STATION 9

M/V Hugh M. Smith: Cruise 20, 26°57'N, 155°01'W, March 13, 1953. Messenger time: first cast 2028 GCT, second cast 2209 GCT. Weather: 02, cloud coverage 8. Wind: 110°, 16 kt. Sea: 5-8 ft. Wire angle: first cast 22°, second cast 24°. Depth of water: 3000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	20.40				
10	20.88				
28	20.71				
56	20.68				
113	19.73				
226	14.40				
340	11.07				
448	08.46				
563	06.26				
671	04.96				
671	05.04				
894	03.90				
1110	03.44				
1319	03.06				

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)

STATION 10

M/V Hugh M. Smith: Cruise 20, 25°54'N, 154°57'W, March 14, 1953. Messenger time: 0913 GCT. Weather: 00, cloud coverage not recorded. Wind: 080°, 15 kt. Sea: 3-5 ft. Wire angle: 20°. Depth of water: 2900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	21.70	35.26	24.52		
09	21.70	35.27	24.52		
24	21.69	35.28	24.54		
52	21.11	35.32	24.72		
105	20.05	35.24	24.95		
210	15.38	34.50	25.52		
315	11.61	34.22	26.07		
426	08.52	34.01	26.44		
533	06.74	34.06	26.74		
641	05.52	34.13	26.95		
851	04.22	34.34	27.26		
1064	03.76	34.44	27.39		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	21.67	35.26	24.53	0.000	1.737
10	21.70	35.27	24.52	0.034	1.703
20	21.69	35.28	24.54	0.068	1.669
30	21.68	35.29	24.55	0.102	1.635
50	21.20	35.32	24.70	0.169	1.568
75	20.68	35.30	24.83	0.250	1.488
100	20.18	35.26	24.93	0.328	1.410
150	18.61	35.03	25.17	0.476	1.261
200	16.40	34.65	25.40	0.615	1.123
250	13.48	34.34	25.80	0.738	0.999
300	12.03	34.24	26.01	0.848	0.890
400	09.15	34.04	26.36	1.040	0.698
500	07.16	34.04	26.66	1.202	0.536
600	05.92	34.10	26.87	1.339	0.398
700	05.00	34.20	27.07	1.457	0.281
800	04.44	34.30	27.20	1.559	0.178
1000	03.84	34.42	27.36	1.737	0.000

STATION 11

M/V Hugh M. Smith: Cruise 20, 24°49'N, 154°58'W, March 14, 1953. Messenger time: 1924 GCT. Weather: 02, cloud coverage 2. Wind: 080°, 16 kt. Sea: 5-8 ft. Wire angle: 09°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	21.80	35.05	24.33		
10	21.82	35.04	24.32		
25	21.83	35.17	24.42		
55	22.09	35.27	24.42		
111	21.50	35.42	24.69		
222	17.48	34.86	25.31		
333	11.52	34.21	26.08		
449	08.24	34.11	26.56		
560	06.14	34.04	26.80		
670	05.01	34.13	27.01		
887	04.27	34.40	27.30		
1102	03.67	34.56	27.49		
1308	03.14	34.52	27.51		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	21.81	35.05	24.33	0.000	1.809
10	21.82	35.04	24.32	0.036	1.773
20	21.82	35.14	24.39	0.072	1.737
30	21.83	35.19	24.43	0.107	1.702
50	21.88	35.25	24.46	0.178	1.632
75	22.12	35.33	24.45	0.265	1.544
100	21.71	35.40	24.62	0.352	1.458
150	20.35	35.28	24.90	0.514	1.295
200	18.65	35.01	25.14	0.666	1.144
250	15.82	34.64	25.53	0.802	1.007
300	12.98	34.31	25.88	0.922	0.888
400	09.45	34.13	26.38	1.120	0.690
500	07.15	34.06	26.68	1.280	0.530
600	05.58	34.04	26.87	1.416	0.394
700	04.92	34.18	27.06	1.534	0.275
800	04.53	34.30	27.19	1.637	0.172
1000	03.95	34.53	27.44	1.809	0.000

STATION 12

M/V Hugh M. Smith: Cruise 20, 23°34'N, 155°02'W, March 15, 1953. Messenger time: first cast 0608 GCT, second cast 0633 GCT. Weather: 02, cloud coverage 5. Wind: 090°, 21 kt. Sea: 5-8 ft. Wire angle: first cast 26°, second cast 32°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	22.20	35.03	24.20		
09	22.19	35.04	24.22		
23	22.20	35.08	24.24		
51	22.25	35.28	24.38		
101	21.54	35.38	24.65		
188	18.05	34.99	25.27		
282	12.50	34.34	26.00		
382	08.84	34.15	26.50		
478	06.70	34.13	26.80		
574	05.64	34.34 1/	27.10		
765	04.66	34.56 1/	27.39		
959	04.14	34.75 1/	27.59		
1246	03.63	34.49	27.45		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	22.20	35.03	24.20	0.000	1.690
10	22.19	35.04	24.21	0.037	1.653
20	22.20	35.07	24.23	0.074	1.616
30	22.22	35.13	24.27	0.111	1.579
50	22.25	35.27	24.37	0.184	1.506
75	22.08	35.35	24.48	0.272	1.418
100	21.62	35.38	24.63	0.358	1.332
150	19.44	35.18	25.06	0.515	1.175
200	17.67	34.94	25.32	0.657	1.033
250	14.07	34.49	25.79	0.782	0.908
300	11.82	34.30	26.09	0.889	0.801
400	08.40	34.14	26.55	1.067	0.623
500	06.36	34.16	26.86	1.208	0.482
600	05.46	34.26	27.06	1.322	0.368
700	04.94	34.33	27.18	1.424	0.266
800	04.56	34.38	27.25	1.518	0.172
1000	04.03	34.44	27.37	1.690	0.000

1/ Doubtful salinities not used for interpolated tabulation.

STATION 13

M/V Hugh M. Smith: Cruise 20, 22°34'N, 155°02'W, March 15, 1953. Messenger time: 1537 GCT. Weather: 16, cloud coverage 8. Wind: 070°, 17 kt. Sea: 8-12 ft. Wire angle: 18°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.10	35.02	23.95		
10	23.07	35.03	23.96		
24	23.08	35.02	23.95		
53	22.94	35.31	24.21		
106	21.75	35.37	24.59		
212	16.48	34.70	25.42		
318	10.68	34.30	26.31		
430	07.82	34.09	26.61		
536	05.82	34.26	27.01		
643	05.00	34.26	27.11		
850	04.40	-	-		
1058	03.84	34.31	27.28		
1260	03.32	34.29	27.31		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.08	35.02	23.94	0.000	1.735
10	23.07	35.03	23.95	0.040	1.695
20	23.08	35.02	23.94	0.079	1.656
30	23.12	35.04	23.94	0.119	1.625
50	23.12	35.30	24.14	0.197	1.538
75	22.50	35.36	24.36	0.289	1.446
100	21.86	35.37	24.55	0.377	1.358
150	20.02	35.15	24.88	0.541	1.194
200	17.22	34.78	25.31	0.687	1.048
250	13.99	34.53	25.84	0.812	0.923
300	11.42	34.36	26.22	0.914	0.821
400	08.60	34.11	26.50	1.088	0.647
500	06.34	34.23	26.92	1.229	0.506
600	05.30	34.26	27.07	1.343	0.392
700	04.79	34.27	27.14	1.447	0.288
800	04.51	34.28	27.18	1.546	0.189
1000	04.00	34.30	27.25	1.735	0.000

STATION 14

M/V Hugh M. Smith: Cruise 20, 21°28'N, 154°51'W, March 16, 1953. Messenger time: 0135 GCT. Weather: 01, cloud coverage 6. Wind: 070°, 24 kt. Sea: 12-20 ft. Wire angle: 13°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.00	35.06	24.01		
10	22.94	35.06	24.02		
25	22.95	35.07	24.02		
55	22.51	35.32	24.34		
110	21.00	35.25	24.70		
220	15.52	34.70	25.65		
330	10.33	34.16	26.26		
444	07.46	34.09	26.66		
554	05.74	34.24	27.01		
663	05.06	34.34	27.17		
876	04.17	34.50	27.39		
1091	03.46	34.52	27.48		
1296	03.01	34.58	27.57		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	22.96	35.06	24.01	0.000	1.674
10	22.94	35.06	24.01	0.039	1.635
20	22.95	35.07	24.02	0.078	1.596
30	22.94	35.10	24.04	0.117	1.557
50	22.60	35.31	24.30	0.192	1.482
75	21.99	35.31	24.47	0.282	1.392
100	21.37	35.28	24.62	0.367	1.307
150	19.23	35.07	25.03	0.526	1.148
200	16.44	34.80	25.51	0.664	1.010
250	14.12	34.54	25.82	0.784	0.890
300	11.62	34.27	26.11	0.890	0.784
400	08.50	34.10	26.51	1.069	0.605
500	06.42	34.15	26.84	1.213	0.461
600	05.40	34.29	27.08	1.330	0.344
700	04.91	34.38	27.21	1.429	0.245
800	04.47	34.46	27.32	1.518	0.156
1000	03.75	34.52	27.45	1.674	0.000

STATION 15

M/V Hugh M. Smith: Cruise 20, 21°02'N, 154°20'W, March 16, 1953. Messenger time: first cast 0907 GCT, second cast 0945 GCT. Weather: 00, cloud coverage not recorded. Wind: 070°, 18 kt. Sea: 8-12 ft. Wire angle: first cast 21°, second cast 26°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	22.90	35.08	24.04		
09	22.93	35.08	24.04		
28	22.93	35.08	24.04		
56	22.48	35.34	24.36		
112	20.89	35.31	24.78		
225	16.92	34.74	25.35		
337	10.20	34.13	26.26		
446	07.58	34.07	26.63		
559	05.86	34.14	26.91		
667	05.15	34.32	27.14		
893	04.13	34.43	27.34		
1105	03.48	34.51	27.47		
1307	02.97	34.54	27.54		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	22.92	35.08	24.04	0.000	1.740
10	22.93	35.08	24.04	0.039	1.701
20	22.93	35.08	24.04	0.078	1.662
30	22.90	35.08	24.04	0.117	1.623
50	22.67	35.31	24.28	0.192	1.548
75	22.00	35.35	24.50	0.282	1.458
100	21.33	35.34	24.68	0.366	1.373
150	19.42	35.13	25.03	0.524	1.215
200	18.34	34.96	25.18	0.672	1.068
250	15.15	34.55	25.61	0.805	0.935
300	12.02	34.27	26.04	0.918	0.821
400	08.58	34.08	26.48	1.104	0.636
500	06.58	34.10	26.79	1.253	0.487
600	05.50	34.22	27.02	1.376	0.363
700	04.97	34.36	27.20	1.481	0.259
800	04.50	34.41	27.28	1.574	0.166
1000	03.80	34.47	27.41	1.740	0.000

STATION 16

M/V Hugh M. Smith: Cruise 20, 20°35'N, 153°46'W, March 16, 1953. Messenger time: 1755 GCT. Weather: 02, cloud coverage 2. Wind: 080°, 16 kt. Sea: 3-5 ft. Wire angle: 21°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.20	34.69	23.66		
09	23.22	34.69	23.66		
22	23.22	34.67	23.64		
50	23.26	34.82	23.74		
101	22.57	35.19	24.22		
202	18.61	34.92	25.07		
304	11.48	34.05	25.97		
412	07.90	34.01	26.53		
514	06.16	34.08	26.83		
617	05.76	34.25	27.01		
817	04.43	34.39	27.28		
1021	03.96	34.49	27.41		
1216	03.44	34.58	27.53		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.22	34.69	23.66	0.000	1.829
10	23.22	34.69	23.66	0.042	1.787
20	23.22	34.68	23.65	0.085	1.744
30	23.23	34.69	23.65	0.128	1.702
50	23.26	34.82	23.74	0.212	1.617
75	23.27	35.07	23.93	0.315	1.514
100	22.64	35.19	24.20	0.412	1.417
150	20.82	35.14	24.69	0.590	1.239
200	18.67	34.93	25.06	0.748	1.081
250	14.80	34.47	25.63	0.884	0.945
300	11.72	34.16	26.01	0.998	0.832
400	08.28	34.01	26.47	1.184	0.645
500	06.25	34.07	26.81	1.333	0.496
600	05.82	34.23	26.99	1.457	0.372
700	05.17	34.32	27.14	1.566	0.263
800	04.50	34.40	27.28	1.662	0.168
1000	03.99	34.49	27.40	1.829	0.000

STATION 17

M/V Hugh M. Smith: Cruise 20, 19°36'N, 154°14'W, March 17, 1953. Messenger time: 0333 GCT. Weather: 02, cloud coverage 4. Wind: 060°, 18 kt. Sea: 8-12 ft. Wire angle: 00°. Depth of water: 2900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.70	34.45	23.34		
10	23.64	34.44	23.35		
26	23.27	34.92	23.82		
57	22.62	35.22	24.23		
113	20.67	35.17	24.73		
226	13.94	34.23	25.62		
338	08.71	34.04	26.43		
455	06.66	34.13	26.80		
568	05.75	34.29	27.04		
681	05.32	34.37	27.16		
900	04.40	34.45	27.33		
1116	03.86	34.51	27.43		
1327	03.36	34.58	27.54		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.70	34.45	23.34	0.000	1.704
10	23.64	34.44	23.35	0.046	1.658
20	23.64	34.58	23.45	0.090	1.613
30	23.15	35.02	23.93	0.133	1.571
50	22.74	35.21	24.19	0.210	1.494
75	22.32	35.24	24.33	0.303	1.401
100	21.30	35.22	24.60	0.390	1.313
150	19.16	34.97	24.98	0.552	1.152
200	16.85	34.61	25.27	0.698	1.006
250	11.54	34.10	25.99	0.820	0.884
300	09.81	34.04	26.25	0.918	0.786
400	07.50	34.08	26.64	1.084	0.619
500	06.22	34.20	26.91	1.220	0.484
600	05.60	34.32	27.09	1.334	0.369
700	05.22	34.38	27.18	1.437	0.267
800	04.78	34.42	27.26	1.532	0.172
1000	04.15	34.48	27.38	1.704	0.000

STATION 18

M/V Hugh M. Smith: Cruise 20, 20°02'N, 154°44'W, March 17, 1953. Messenger time: first cast 1038 GCT, second cast 1059 GCT. Weather: 81, cloud coverage not recorded. Wind: 080°, 14 kt. Sea: 3-5 ft. Wire angle: first cast 15°, second cast 18°. Depth of water: 2900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.20	34.90	23.82		
10	23.16	34.92	23.85		
24	22.79	35.21	24.18		
53	22.14	35.38	24.48		
107	21.28	35.38	24.72		
211	16.68	34.57	25.28		
314	10.90	34.05	26.07		
424	07.62	34.11	26.65		
529	06.25	34.21	26.92		
636	05.53	34.33	27.10		
845	04.39	34.41	27.30		
845	04.52	34.45	27.32		
1054	04.02	34.59 1/	27.48		
1256	03.35	34.54	27.50		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	23.18	34.90	23.83	0.000	1.713
10	23.16	34.92	23.85	0.041	1.673
20	22.94	35.09	24.04	0.080	1.633
30	22.64	35.27	24.26	0.118	1.595
50	22.22	35.38	24.46	0.190	1.523
75	21.75	35.41	24.62	0.276	1.437
100	21.39	35.40	24.71	0.359	1.354
150	19.47	35.16	25.04	0.516	1.197
200	17.42	34.79	25.27	0.661	1.052
250	13.81	34.31	25.71	0.790	0.924
300	11.53	34.09	25.99	0.902	0.812
400	08.20	34.09	26.55	1.086	0.628
500	06.55	34.19	26.86	1.228	0.485
600	05.72	34.30	27.06	1.346	0.367
700	05.11	34.38	27.19	1.450	0.264
800	04.60	34.43	27.29	1.543	0.171
1000	04.15	34.46	27.36	1.713	0.000

1/ Doubtful salinity not used for interpolated tabulations.

STATION 19

M/V Hugh M. Smith: Cruise 20, 20°30'N, 155°19'W, March 17, 1953. Messenger time: first cast 1808 GCT, second cast 1843 GCT. Weather: 02, cloud coverage 1. Wind: 090°, 15 kt. Sea: 3-5 ft. Wire angle: first cast 31°, second cast 37°. Depth of water: 1400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	22.80	35.21	24.17		
09	22.81	35.20	24.16		
22	22.83	35.23	24.18		
48	22.82	35.21	24.17		
96	21.80	35.40	24.60		
187	18.32	34.96	25.18		
281	11.45	34.12	26.03		
380	08.92	34.11	26.45		
477	06.82	34.15	26.80		
565	05.55	34.19	26.99		
755	04.75	34.41	27.26		
955	04.33	34.48	27.36		
1156	03.51	34.54	27.49		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	22.82	35.21	24.17	0.000	1.720
10	22.81	35.20	24.16	0.038	1.682
20	22.82	35.23	24.18	0.075	1.644
30	22.82	35.22	24.17	0.113	1.607
50	22.82	35.21	24.17	0.188	1.531
75	22.51	35.33	24.34	0.281	1.439
100	21.72	35.41	24.63	0.368	1.351
150	20.41	35.26	24.87	0.531	1.188
200	17.81	34.90	25.26	0.680	1.039
250	13.96	34.37	25.73	0.809	0.910
300	10.88	34.11	26.13	0.917	0.802
400	08.45	34.12	26.54	1.095	0.625
500	06.41	34.16	26.86	1.238	0.482
600	05.29	34.23	27.05	1.356	0.363
700	04.87	34.36	27.21	1.459	0.261
800	04.64	34.42	27.28	1.551	0.169
1000	04.15	34.49	27.39	1.720	0.000

STATION 20

M/V Hugh M. Smith: Cruise 20, 21°50'N, 155°26'W, March 18, 1953. Messenger time: first cast 0606 GCT, second cast 0641 GCT. Weather: 02, cloud coverage not recorded. Wind: 070°, 17 kt. Sea: 5-8 ft. Wire angle: first cast 16°, second cast 22°. Depth of water: 2800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.10	35.22	24.09		
10	23.12	35.19	24.06		
24	23.06	35.18	24.07		
53	23.04	35.21	24.10		
106	22.34	35.37	24.42		
215	18.54	35.01	25.16		
324	10.80	34.05	26.09		
437	07.66	34.01	26.57		
544	05.89	34.10	26.88		
653	04.98	34.23	27.09		
858	04.40	34.41	27.30		
1069	03.81	34.47	27.40		
1271	03.24	34.52	27.50		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	23.12	35.22	24.09	0.000	1.820
10	23.12	35.19	24.06	0.038	1.781
20	23.10	35.18	24.06	0.077	1.742
30	23.05	35.18	24.08	0.116	1.704
50	23.04	35.20	24.09	0.193	1.627
75	23.03	35.28	24.16	0.289	1.531
100	22.49	35.37	24.38	0.381	1.438
150	21.17	35.30	24.69	0.555	1.265
200	18.85	35.05	25.12	0.711	1.108
250	16.62	34.77	25.44	0.851	0.969
300	12.15	34.18	25.95	0.970	0.849
400	08.59	34.00	26.42	1.162	0.657
500	06.51	34.05	26.76	1.316	0.504
600	05.29	34.16	27.00	1.442	0.378
700	04.79	34.27	27.14	1.550	0.270
800	04.51	34.37	27.25	1.646	0.173
1000	04.01	34.45	27.37	1.820	0.000

STATION 21

M/V Hugh M. Smith: Cruise 20, 22°16'N, 160°00'W, March 18, 1953. Messenger time: 1354 GCT. Weather: 01, cloud coverage 3. Wind: 090°, 19 kt. Sea: 3-5 ft. Wire angle: 10°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	22.90	34.92	23.92		
10	22.92	34.93	23.93		
25	22.93	34.93	23.92		
55	22.70	35.36	24.31		
110	21.40	35.31	24.64		
220	15.31	34.49	25.53		
330	10.31	34.07	26.19		
446	07.92	34.13	26.62		
556	05.88	34.18	26.94		
666	05.52	34.35	27.12		
881	04.64	34.43	27.29		
1096	03.86	34.47	27.40		
1301	03.24	34.52	27.50		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	22.92	34.92	23.92	0.000	1.751
10	22.92	34.93	23.92	0.040	1.711
20	22.93	34.93	23.92	0.080	1.671
30	22.93	34.93	23.92	0.120	1.631
50	22.73	35.36	24.31	0.196	1.555
75	22.43	35.36	24.40	0.287	1.465
100	21.70	35.33	24.57	0.374	1.377
150	19.11	35.05	25.05	0.534	1.217
200	16.80	34.72	25.36	0.676	1.075
250	12.91	34.23	25.83	0.800	0.951
300	11.23	34.10	26.05	0.908	0.844
400	08.84	34.09	26.45	1.094	0.658
500	06.75	34.15	26.80	1.244	0.507
600	05.69	34.23	27.01	1.368	0.383
700	05.40	34.38	27.16	1.475	0.276
800	05.00	34.41	27.23	1.573	0.178
1000	04.20	34.45	27.35	1.751	0.000

STATION 22

M/V Hugh M. Smith: Cruise 20, 22°38'N, 156°32'W, March 18, 1953. Messenger time: 2053 GCT. Weather: 02, cloud coverage 1. Wind: 090°, 19 kt. Sea: 5-8 ft. Wire angle: 33°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.30	35.01	23.87		
09	23.31	35.01	23.87		
25	23.32	35.02	23.88		
51	23.31	35.03	23.89		
101	22.05	35.27	24.43		
199	18.40	34.93 1/	25.14		
294	12.68	34.22 1/	25.87		
388	09.38	33.98 1/	26.28		
485	07.10	34.07	26.69		
577	05.98	34.12	26.88		
767	04.74	34.27	27.15		
950	04.14	34.40	27.32		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.32	35.01	23.87	0.000	1.884
10	23.31	35.01	23.87	0.040	1.843
20	23.32	35.02	23.88	0.081	1.803
30	23.32	35.02	23.88	0.121	1.762
50	23.31	35.03	23.89	0.202	1.681
75	23.31	35.08	23.93	0.303	1.581
100	22.13	35.26	24.00	0.403	1.481
150	19.99	35.09	24.85	0.581	1.302
200	18.39	34.94	25.15	0.733	1.150
250	16.20	34.65	25.45	0.872	1.012
300	12.40	34.20	25.86	0.993	0.890
400	09.01	34.00	26.34	1.194	0.690
500	06.88	34.07	26.73	1.353	0.531
600	05.75	34.14	26.94	1.483	0.400
700	05.07	34.22	27.06	1.598	0.285
800	04.60	34.29	27.18	1.703	0.181
1000	04.01	34.43	27.36	1.884	0.000

1/ Salinities corrected for buret misreading; values doubtful but used for interpolated tabulations.

STATION 23

M/V Hugh M. Smith: Cruise 20, 23°08'N, 157°00'W, March 19, 1953. Messenger time: 0412 GCT. Weather: 02, cloud coverage 3. Wind: 070°, 18 kt. Sea: 5-8 ft. Wire angle: 07°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
03	23.30	35.07	23.92		
13	23.26	35.06	23.93		
28	23.26	35.06	23.93		
58	23.18	35.07	23.96		
114	22.24	35.28	24.38		
226	18.62	34.99	25.13		
338	11.16	34.14	26.10		
454	07.70	34.02	26.57		
566	05.85	34.06	26.85		
678	04.94	34.19	27.06		
896	04.30	34.41	27.31		
1113	03.73	34.46	27.41		
1320	03.18	34.51	27.50		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.26	35.07	23.93	0.000	1.913
10	23.26	35.06	23.93	0.040	1.873
20	23.26	35.06	23.93	0.080	1.833
30	23.26	35.06	23.93	0.120	1.793
50	23.20	35.06	23.94	0.200	1.713
75	23.18	35.09	23.97	0.299	1.613
100	22.48	35.26	24.30	0.395	1.518
150	21.43	35.22	24.56	0.574	1.339
200	19.38	35.04	24.97	0.737	1.176
250	17.88	34.88	25.23	0.885	1.028
300	14.38	34.45	25.71	1.016	0.897
400	09.05	34.01	26.36	1.223	0.689
500	06.81	34.01	26.69	1.383	0.530
600	05.45	34.07	26.91	1.517	0.396
700	04.84	34.19	27.06	1.633	0.280
800	04.56	34.34	27.22	1.735	0.178
1000	04.03	34.42	27.35	1.913	0.000

STATION 24

M/V Hugh M. Smith: Cruise 20, 23°38'N, 157°32'W, March 19, 1953. Messenger time: 1100 GCT. Weather: 02, cloud coverage not recorded. Wind: 080°, 18 kt. Sea: 5-8 ft. Wire angle: 21°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.40	35.16	23.96		
09	23.34	35.14	23.96		
23	23.36	35.16	23.97		
51	23.00	35.30	24.18		
103	-	35.41	-		
206	16.76	34.67	25.34		
310	11.23	34.14	26.08		
420	08.11	34.07	26.55		
524	06.25	34.10	26.83		
628	05.08	34.16	27.02		
833	04.40	34.44	27.32		
1039	03.84	34.50	27.43		
1237	03.34	34.52	27.49		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.36	35.16	23.97	0.000	1.768
10	23.35	35.14	23.96	0.040	1.728
20	23.36	35.15	23.96	0.079	1.688
30	23.34	35.19	24.00	0.119	1.649
50	23.01	35.29	24.17	0.196	1.572
75	22.74	35.30	24.26	0.289	1.478
100	21.61	35.25	24.53	0.379	1.389
150	19.80	35.02	24.85	0.545	1.223
200	17.18	34.71	25.27	0.694	1.074
250	14.13	34.39	25.71	0.823	0.945
300	11.68	34.16	26.02	0.934	0.834
400	08.60	34.07	26.47	1.120	0.647
500	06.62	34.08	26.77	1.271	0.496
600	05.32	34.13	26.97	1.398	0.370
700	04.76	34.29	27.16	1.506	0.261
800	04.48	34.40	27.28	1.600	0.167
1000	03.92	34.48	27.40	1.768	0.000

STATION 25A

M/V Hugh M. Smith: Cruise 20, 23°33'N, 159°06'W, March 19, 1953. Messenger time: 2212 GCT. Weather: 16, cloud coverage 4. Wind: 090°, 21 kt. Sea: 5-8 ft. Wire angle: 24°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	22.70	35.29	24.26		
09	22.70	35.27	24.25		
23	22.68	35.27	24.25		
50	22.65	35.28	24.27		
101	19.90	35.08	24.87		
204	14.84	34.42	25.58		
262	11.56	34.18	26.05		
345	08.80	34.04	26.41		
427	06.83	34.00	26.68		
509	05.90	34.05	26.84		
670	04.74	34.23	27.12		
836	04.29	34.40	27.30		
999	03.88	34.48	27.41		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	22.70	35.29	24.25	0.000	1.655
10	22.70	35.27	24.24	0.037	1.618
20	22.68	35.27	24.25	0.074	1.581
30	22.67	35.27	24.25	0.111	1.544
50	22.65	35.28	24.26	0.184	1.471
75	22.05	35.30	24.45	0.274	1.381
100	19.93	35.08	24.86	0.358	1.297
150	18.00	34.84	25.16	0.507	1.148
200	15.60	34.51	25.48	0.643	1.012
250	12.21	34.22	25.96	0.760	0.895
300	10.26	34.11	26.23	0.859	0.796
400	07.36	34.00	26.60	1.027	0.628
500	05.98	34.04	26.81	1.168	0.487
600	05.15	34.14	26.99	1.290	0.365
700	04.62	34.28	27.16	1.395	0.260
800	04.38	34.37	27.26	1.489	0.166
1000	03.88	34.48	27.40	1.655	0.000

STATION 25

M/V Hugh M. Smith: Cruise 20, 23°07'N, 158°30'W, March 20, 1953. Messenger time: 0539 GCT. Weather: 02, cloud coverage 8. Wind: 090°, 18 kt. Sea: 5-8 ft. Wire angle: 11°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
04	22.50	35.34	24.35		
14	22.51	35.37	24.37		
29	22.52	35.35	24.36		
59	22.24	35.36	24.44		
115	-	35.30	-		
227	14.84	34.46	25.61		
338	09.86	34.10	26.29		
455	07.10	34.03	26.66		
567	05.91	34.13	26.90		
679	04.69	34.25	27.14		
897	03.91	34.42	27.36		
897	03.97	34.42	27.35		
1114	03.52	34.52	27.47		
1320	03.10	34.55	27.54		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	22.52	35.34	24.34	0.000	1.693
10	22.52	35.36	24.36	0.036	1.657
20	22.51	35.36	24.36	0.072	1.621
30	22.52	35.35	24.35	0.107	1.586
50	22.40	35.36	24.39	0.179	1.514
75	21.98	35.35	24.50	0.267	1.426
100	20.42	35.21	24.82	0.350	1.343
150	18.67	34.97	25.10	0.502	1.191
200	16.27	34.62	25.41	0.641	1.052
250	14.27	34.41	25.69	0.766	0.927
300	11.30	34.18	26.10	0.875	0.818
400	08.20	34.04	26.51	1.054	0.639
500	06.62	34.06	26.75	1.203	0.490
600	05.48	34.18	26.99	1.329	0.364
700	04.59	34.26	27.15	1.436	0.257
800	04.18	34.35	27.27	1.529	0.164
1000	03.72	34.48	27.42	1.693	0.000

STATION 26

M/V Hugh M. Smith: Cruise 20, 22°42'N, 157°57'W, March 20, 1953. Messenger time: first cast 1320 GCT, second cast 1420 GCT, third cast 1514 GCT. Weather: 80, cloud coverage not recorded. Wind: 090°, 25 kt. Sea: 8-12 ft. Wire angle: first cast 25°, second cast 28°, third cast 28°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.00	35.31	24.19		
23	22.96	35.33	24.21		
50	22.92	35.34	24.24		
99	22.24	35.34	24.43		
196	17.20	34.78	25.32		
293	12.14	34.16	25.93		
394	08.79	34.05	26.43		
504	06.92	34.09	26.74		
604	05.70	34.14	26.93		
803	04.32	34.34	27.25		
1005	03.73	34.45	27.40		
1208	03.30	34.51	27.49		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	22.98	35.31	24.19	0.000	1.766
10	22.97	35.32	24.20	0.037	1.729
20	22.96	35.33	24.21	0.075	1.691
30	22.95	35.33	24.21	0.112	1.654
50	22.92	35.34	24.23	0.186	1.580
75	22.61	35.34	24.32	0.278	1.488
100	22.23	35.34	24.43	0.368	1.398
150	19.30	35.08	25.02	0.531	1.235
200	17.05	34.76	25.33	0.674	1.092
250	14.19	34.38	25.68	0.801	0.965
300	11.82	34.14	25.97	0.914	0.852
400	08.62	34.05	26.45	1.102	0.664
500	06.98	34.09	26.72	1.255	0.511
600	05.74	34.13	26.91	1.386	0.380
700	04.90	34.23	27.09	1.499	0.267
800	04.34	34.33	27.23	1.597	0.169
1000	03.74	34.45	27.39	1.766	0.000

STATION 27

M/V Hugh M. Smith: Cruise 20, 22°12'N, 157°22'W, March 21, 1953. Messenger time: first cast 0042 GCT, second cast 0121 GCT. Weather: 02, cloud coverage 5. Wind: 100°, 20 kt. Sea: 8-12 ft. Wire angle: first cast 32°, second cast 40°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.10	34.96	23.90		
10	23.07	34.90	23.86		
27	23.04	34.91	23.87		
52	23.01	34.88	23.86		
101	22.89	35.21	24.15		
197	19.50	35.16	25.03		
290	13.18	34.28	25.82		
381	09.20	34.09	26.39		
478	07.22	34.07	26.68		
506	06.84	34.11	26.76		
680	05.44	34.32	27.11		
853	04.84	34.58	27.38		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	23.08	34.96	23.90	0.000	1.831
10	23.07	34.90	23.85	0.040	1.791
20	23.05	34.91	23.87	0.081	1.750
30	23.04	34.91	23.87	0.121	1.710
50	23.02	34.88	23.85	0.203	1.628
75	22.96	35.04	23.99	0.303	1.528
100	22.90	35.21	24.14	0.400	1.431
150	21.20	35.29	24.67	0.579	1.252
200	19.44	35.15	25.04	0.737	1.094
250	16.35	34.74	25.48	0.876	0.955
300	12.70	34.24	25.88	0.996	0.835
400	08.67	34.08	26.47	1.188	0.643
500	06.94	34.10	26.73	1.340	0.491
600	06.00	34.22	26.95	1.468	0.363
700	05.36	34.34	27.13	1.579	0.252
800	04.98	34.49	27.29	1.674	0.157
1000	04.60	34.70	27.50	1.831	0.000

STATION 28

M/V Hugh M. Smith: Cruise 20, 21°46'N, 156°53'W, March 21, 1953. Messenger time: first cast 0924 GCT, second cast 1002 GCT, third cast 1040 GCT. Weather: 00, cloud coverage 3. Wind: 100°, 23 kt. Sea: 5-8 ft. Wire angle: first cast 40°, second cast 46°, third cast 50°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.00	34.94	23.92		
08	22.98	34.93	23.91		
19	23.00	34.95	23.92		
42	23.02	34.97	23.93		
84	22.69	35.34	24.30		
167	20.25	35.23	24.89		
249	16.98	34.75	25.34		
335	11.58	34.16	26.03		
418	09.14	34.16	26.46		
502	-	-	-		
617	05.71	34.20	26.98		
783	04.70	34.40	27.26		
948	04.04	34.46	27.38		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	22.98	34.94	23.91	0.000	1.847
10	22.99	34.93	23.90	0.040	1.807
20	23.00	34.95	23.91	0.080	1.767
30	23.01	34.96	23.92	0.120	1.727
50	23.04	35.00	23.94	0.200	1.647
75	22.87	35.30	24.21	0.297	1.550
100	22.42	35.34	24.37	0.389	1.458
150	21.00	35.29	24.73	0.560	1.287
200	18.80	35.04	25.12	0.715	1.132
250	16.87	34.73	25.35	0.856	0.991
300	13.32	34.27	25.78	0.981	0.866
400	09.60	34.16	26.38	1.183	0.664
500	07.38	34.15	26.71	1.340	0.507
600	05.90	34.15	26.91	1.472	0.375
700	05.14	34.32	27.14	1.584	0.263
800	04.61	34.40	27.26	1.679	0.168
1000	03.98	34.47	27.38	1.847	0.000

STATION 29

M/V Hugh M. Smith: Cruise 20, 21°22'N, 156°18'W, March 21, 1953. Messenger time: 1956 GCT. Weather: 18, cloud coverage 6. Wind: 110°, 24 kt. Sea: 5-8 ft. Wire angle: 38°. Depth of water: 1100 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	22.90	35.12	24.07		
09	22.92	35.12	24.07		
24	22.92	35.13	24.08		
47	22.91	35.13	24.08		
95	22.20	35.37	24.46		
191	18.97	35.10	25.12		
287	12.32	34.15	25.89		
377	09.31	34.12	26.40		
473	07.14	34.11	26.72		
529	05.83	34.11	26.89		
651	05.40	34.32	27.11		
800	04.64	34.41	27.27		
936	04.06	34.46	27.37		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	22.92	35.12	24.06	0.000	1.772
10	22.92	35.12	24.06	0.039	1.733
20	22.92	35.13	24.07	0.077	1.695
30	22.92	35.13	24.07	0.116	1.656
50	22.89	35.14	24.09	0.193	1.579
75	22.72	35.27	24.23	0.287	1.485
100	22.10	35.37	24.49	0.378	1.394
150	20.81	35.32	24.80	0.545	1.227
200	18.80	35.08	25.15	0.697	1.075
250	15.49	34.51	25.50	0.834	0.938
300	11.62	34.13	26.00	0.950	0.822
400	08.82	34.12	26.47	1.135	0.637
500	06.36	34.10	26.81	1.283	0.489
600	05.58	34.23	27.01	1.404	0.368
700	05.18	34.36	27.16	1.510	0.262
800	04.64	34.41	27.27	1.604	0.168
1000	03.96	34.47	27.39	1.772	0.000

STATION 30

M/V Hugh M. Smith: Cruise 20, 20°55'N, 155°44'W, March 22, 1953. Messenger time: 0410 GCT. Weather: 18, cloud coverage 8. Wind: 110°, 18 kt. Sea: 5-8 ft. Wire angle: 12°. Depth of water: 1800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
02	23.40	35.08	23.90		
12	23.40	35.08	23.90		
32	23.00	35.19	24.10		
62	23.06	35.36	24.21		
123	21.30	35.26	24.63		
242	16.70	34.81	25.46		
360	09.57	34.27	26.47		
474	06.73	34.19	26.84		
593	05.38	34.20	27.02		
708	05.04	34.36	27.19		
941	04.19	34.47	27.37		
1173	03.46	34.58	27.53		
1377	02.96	34.56	27.56		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	23.43	35.08	23.89	0.000	1.757
10	23.40	35.08	23.89	0.040	1.717
20	23.12	35.10	23.99	0.080	1.677
30	23.02	35.17	24.07	0.119	1.638
50	23.02	35.31	24.18	0.195	1.562
75	22.94	35.37	24.25	0.289	1.468
100	22.63	35.37	24.34	0.380	1.377
150	20.62	35.20	24.76	0.552	1.205
200	18.80	35.04	25.12	0.706	1.051
250	16.42	34.78	25.50	0.843	0.914
300	12.40	34.40	26.06	0.958	0.799
400	08.39	34.22	26.62	1.134	0.623
500	06.35	34.19	26.89	1.269	0.488
600	05.33	34.21	27.03	1.387	0.369
700	05.07	34.34	27.17	1.492	0.264
800	04.72	34.41	27.26	1.587	0.169
1000	03.98	34.50	27.41	1.757	0.000

STATION 31

M/V Hugh M. Smith: Cruise 20, 19°47'N, 156°14'W, March 22, 1953. Messenger time: 1458 GCT. Weather: 01, cloud coverage not recorded. Wind: 180°, 07 kt. Sea: < 1 ft. Wire angle: 32°. Depth of water: 2100 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.90	35.03	23.72		
08	23.92	34.97	23.66		
21	23.84	35.01	23.72		
46	23.38	35.17	23.97		
90	22.01	35.25	24.42		
173	18.80	35.03	25.11		
254	13.54	34.36	25.81		
340	08.90	34.13	26.47		
423	07.08	34.18	26.78		
506	06.43	34.22	26.90		
652	05.52	34.40	27.16		
816	04.94	34.45	27.27		
975	04.30	34.54	27.41		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	23.92	35.04	23.72	0.000	1.709
10	23.90	34.97	23.67	0.042	1.667
20	23.87	35.02	23.72	0.084	1.625
30	23.82	35.09	23.78	0.126	1.583
50	23.26	35.20	24.03	0.206	1.503
75	22.46	35.23	24.28	0.302	1.408
100	21.50	35.23	24.55	0.391	1.319
150	19.58	35.11	24.97	0.553	1.156
200	17.37	34.86	25.34	0.698	1.012
250	13.70	34.36	25.77	0.824	0.886
300	10.96	34.16	26.15	0.930	0.779
400	07.38	34.16	26.73	1.097	0.612
500	06.48	34.22	26.90	1.229	0.480
600	05.80	34.33	27.07	1.345	0.364
700	05.30	34.42	27.20	1.448	0.262
800	04.98	34.45	27.27	1.541	0.168
1000	04.21	34.54	27.42	1.709	0.000

STATION 32

M/V Hugh M. Smith: Cruise 20, 20°09'N, 156°37'W, March 22, 1953. Messenger time: first cast 2009 GCT, second cast 2037 GCT, third cast 2117 GCT. Weather: 02, cloud coverage 7. Wind: 060°, 24 kt. Sea: 3-5 ft. Wire angle: first cast 45°, second cast 56°, third cast 59°. Depth of water: 1600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.80	35.05	23.76		
07	23.82	35.07	23.77		
21	23.84	35.05	23.75		
42	23.82	35.07	23.77		
82	22.16	35.32	24.44		
155	18.76	35.05	25.14		
197	17.36	34.81	25.30		
259	12.29	34.27	25.99		
324	09.66	34.13	26.35		
388	08.35	34.16	26.58		
484	06.92	34.18	26.81		
571	05.96	34.23	26.97		
658	05.40	34.34	27.13		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.84	35.05	23.75	0.000	1.715
10	23.83	35.06	23.76	0.042	1.674
20	23.84	35.04	23.74	0.083	1.632
30	23.83	35.05	23.75	0.125	1.590
50	23.83	35.08	23.77	0.208	1.507
75	22.32	35.32	24.39	0.305	1.410
100	21.77	35.32	24.55	0.393	1.323
150	18.87	35.06	25.12	0.552	1.164
200	16.95	34.77	25.37	0.692	1.024
250	12.90	34.31	25.90	0.814	0.902
300	10.36	34.14	26.24	0.915	0.801
400	08.14	34.16	26.61	1.084	0.632
500	06.72	34.18	26.83	1.225	0.491
600	05.76	34.24	27.00	1.348	0.368
700	05.27	34.36	27.16	1.456	0.260 1/

1/ Value obtained from adjacent stations.

STATION 33

M/V Hugh M. Smith: Cruise 20, 20°38'N, 157°05'W, March 23, 1953. Messenger time: 0343 GCT. Weather: 03, cloud coverage 7. Wind: 010°, 9 kt. Sea: < 1 ft. Wire angle: 07°. Depth of water: 300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.10	34.94	23.59		
10	24.11	34.92	23.57		
25	24.11	34.95	23.59		
55	24.04	34.98	23.63		
110	23.02	35.30	24.17		
220	17.68	34.87	25.27		
329	09.64	34.21	26.42		
445	07.52	34.19	26.73		
555	06.22	34.22	26.93		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.11	34.94	23.58		
10	24.11	34.92	23.57		
20	24.11	34.98	23.61		
30	24.10	34.95	23.60		
50	24.04	34.97	23.63		
75	24.05	35.06	23.69		
100	23.20	35.28	24.11		
150	20.78	35.15	24.68		
200	18.20	34.92	25.18		
250	14.90	34.62	25.72		
300	10.72	34.26	26.27		
400	08.26	34.19	26.62		
500	06.76	34.20	26.84		
600	06.10	34.22	26.95		

STATION 34

M/V Hugh M. Smith: Cruise 20, 21°05'N, 157°36'W, March 23, 1953. Messenger time: 0956 GCT. Weather: 00, cloud coverage not recorded. Wind: 060°, 22 kt. Sea: 5-8 ft. Wire angle: 00°. Depth of water: 25 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.00				
10	23.96				
25	23.84				

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)

STATION 35

M/V Hugh M. Smith: Cruise 20, 21°20'N, 158°18'W, March 24, 1953. Messenger time: 0514 GCT. Weather: 02, cloud coverage 2. Wind: 080°, 13 kt. Sea: 1-3 ft. Wire angle: 09°. Depth of water: 800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
01	23.86	35.22	23.87		
11	23.85	35.21	23.86		
26	23.48	35.22	23.98		
55	22.78	35.39	24.31		
109	20.88	35.25	24.73		
214	16.40	34.67	25.42		
318	10.97	34.20	26.18		
318	10.91	34.20	26.19		
428	07.77	34.20	26.70		
531	06.57	34.23	26.89		
634	05.70	34.21	26.99		
836	04.84	34.48	27.30		
1043	03.96	34.54	27.45		
1245	03.44	34.56	27.51		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.86	35.22	23.86	0.000	1.736
10	23.85	35.21	23.86	0.040	1.696
20	23.83	35.21	23.87	0.081	1.655
30	23.36	35.24	24.03	0.121	1.615
50	22.86	35.39	24.28	0.196	1.540
75	22.30	35.37	24.43	0.286	1.450
100	21.37	35.30	24.64	0.372	1.364
150	19.80	35.10	24.90	0.534	1.202
200	17.02	34.75	25.33	0.679	1.057
250	14.20	34.43	25.72	0.805	0.931
300	11.70	34.22	26.05	0.915	0.821
400	08.42	34.20	26.60	1.092	0.644
500	06.84	34.22	26.84	1.232	0.504
600	05.92	34.21	26.96	1.355	0.381
700	05.40	34.28	27.07	1.468	0.268
800	05.01	34.43	27.24	1.568	0.168
1000	04.12	34.54	27.42	1.736	0.000

STATION 36

M/V Hugh M. Smith: Cruise 20, 22°01'N, 158°38'W, March 24, 1953. Messenger time: 1240 GCT. Weather: 80, cloud coverage 8. Wind: 080°, 13 kt. Sea: 3-5 ft. Wire angle: 10°. Depth of water: 1600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.30	35.30	24.09		
10	23.32	35.38	24.15		
30	23.22	35.44	24.22		
59	22.82	35.44	24.34		
115	21.74	35.52	24.70		
225	17.64	34.95	25.34		
336	10.26	34.22	26.32		
443	07.96	34.17	26.65		
553	05.86	34.15	26.92		
660	-	34.32	-		
881	-	34.51	-		
1096	03.72	34.56	27.49		
1309	03.22	34.65	27.61		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	23.32	35.30	24.08	0.000	1.730
10	23.32	35.38	24.14	0.038	1.692
20	23.29	35.42	24.18	0.076	1.654
30	23.22	35.44	24.22	0.113	1.617
50	22.86	35.44	24.32	0.187	1.543
75	22.77	35.45	24.36	0.277	1.453
100	21.96	35.51	24.63	0.364	1.366
150	21.00	35.47	24.87	0.526	1.204
200	18.77	35.12	25.19	0.676	1.054
250	16.20	34.76	25.53	0.811	0.919
300	12.27	34.36	26.05	0.925	0.805
400	08.86	34.18	26.51	1.107	0.623
500	06.70	34.15	26.81	1.252	0.478
600	05.45	34.20	27.01	1.375	0.355
700	04.98	34.36	27.19	1.479	0.251
800	04.60	34.45	27.30	1.570	0.160
1000	03.97	34.53	27.43	1.730	0.000

STATION 37

M/V Hugh M. Smith: Cruise 20, 22°20'N, 159°03'W, March 24, 1953. Messenger time: 1839 GCT. Weather: 03, cloud coverage 4. Wind: 080°, 14 kt. Sea: 3-5 ft. Wire angle: 10°. Depth of water: 1900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.40	35.21	24.01		
10	23.39	35.24	24.02		
26	23.39	35.24	24.02		
54	22.99	35.24	24.14		
108	22.14	35.33	24.45		
212	18.21	34.85	25.12		
315	12.37	34.17	25.90		
424	08.80	34.11	26.47		
528	06.57	34.18	26.85		
633	05.38	34.18	27.00		
837	04.50	34.34	27.23		
1043	03.92	34.57	27.47		
1243	03.36	34.57	27.53		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	23.38	35.21	24.00	0.000	1.847
10	23.39	35.24	24.02	0.039	1.808
20	23.39	35.24	24.02	0.078	1.769
30	23.39	35.24	24.02	0.117	1.730
50	23.31	35.24	24.04	0.195	1.652
75	22.50	35.26	24.29	0.290	1.557
100	22.44	35.26	24.31	0.381	1.466
150	20.86	35.21	24.71	0.555	1.292
200	18.98	34.95	25.00	0.713	1.134
250	16.20	34.58	25.39	0.856	0.991
300	12.97	34.21	25.80	0.979	0.868
400	09.53	34.11	26.35	1.181	0.666
500	07.07	34.17	26.77	1.336	0.511
600	05.66	34.18	26.96	1.463	0.384
700	04.99	34.22	27.08	1.575	0.272
800	04.62	34.30	27.18	1.677	0.170
1000	04.02	34.55	27.44	1.847	0.000

STATION 37A

M/V Hugh M. Smith: Cruise 20, 22°44'N, 159°38'W, March 25, 1953. Messenger time: 0147 GCT. Weather: 16, cloud coverage 7. Wind: 050°, 16 kt. Sea: 3-5 ft. Wire angle: 18°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.60	35.25	23.97		
10	23.59	35.23	23.96		
24	23.58	35.23	23.96		
52	23.50	35.21	23.97		
104	22.84	35.30	24.23		
203	17.74	34.85	25.24		
302	12.86	34.30	25.90		
408	09.41	34.16	26.41		
508	06.73	34.02	26.71		
609	05.21	34.18	27.02		
809	04.60	34.38	27.25		
1009	03.78	34.50	27.43		
1204	03.25	34.54	27.51		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.60	35.25	23.96	0.000	1.828
10	23.59	35.23	23.95	0.040	1.788
20	23.59	35.23	23.95	0.079	1.749
30	23.56	35.23	23.96	0.119	1.709
50	23.52	35.21	23.96	0.198	1.630
75	23.49	35.25	24.00	0.297	1.531
100	22.90	35.30	24.20	0.394	1.434
150	20.75	35.15	24.69	0.570	1.258
200	17.90	34.87	25.21	0.724	1.104
250	14.90	34.50	25.62	0.856	0.972
300	12.95	34.30	25.88	0.972	0.856
400	09.67	34.17	26.37	1.169	0.659
500	06.90	34.02	26.68	1.328	0.500
600	05.31	34.15	26.98	1.457	0.371
700	04.90	34.29	27.14	1.565	0.263
800	04.63	34.37	27.23	1.661	0.167
1000	03.81	34.50	27.43	1.828	0.000

STATION 38A

M/V Hugh M. Smith: Cruise 20, 22°24'N, 160°13'W, March 25, 1953. Messenger time: 0758 GCT. Weather: 01, cloud coverage 4. Wind: 040°, 17 kt. Sea: 3-5 ft. Wire angle: 35°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.50	35.25	24.00		
09	23.48	35.25	24.00		
25	23.49	35.21	23.97		
49	23.49	35.27	24.02		
95	22.95	35.29	24.19		
184	19.23	35.08	25.04		
274	13.60	34.58	25.96		
362	10.34	34.16	26.26		
455	07.74	34.17	26.68		
546	06.20	34.13	26.86		
736	04.80	34.34	27.20		
925	04.16	34.41	27.32		
1117	03.69	34.47	27.42		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.48	35.25	24.00	0.000	1.793
10	23.48	35.25	24.00	0.039	1.754
20	23.48	35.22	23.98	0.078	1.715
30	23.49	35.21	23.97	0.118	1.675
50	23.49	35.27	24.01	0.197	1.596
75	23.48	35.29	24.03	0.295	1.498
100	22.68	35.29	24.26	0.390	1.403
150	20.20	35.14	24.83	0.562	1.231
200	18.79	35.05	25.13	0.714	1.079
250	15.15	34.73	25.74	0.845	0.948
300	12.44	34.42	26.07	0.954	0.839
400	09.22	34.17	26.45	1.138	0.655
500	06.86	34.14	26.78	1.289	0.504
600	05.65	34.18	26.97	1.414	0.379
700	05.00	34.30	27.14	1.523	0.270
800	04.57	34.37	27.24	1.619	0.174
1000	03.97	34.43	27.35	1.793	0.000

STATION 38

M/V Hugh M. Smith: Cruise 20, 21°30'N, 159°03'W, March 25, 1953. Messenger time: 2005 GCT. Weather: 01, cloud coverage 1. Wind: 080°, 21 kt. Sea: 3-5 ft. Wire angle: 18°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.10	35.30	24.15		
09	23.11	35.31	24.16		
24	23.10	35.29	24.15		
52	22.98	35.36	24.23		
103	21.71	35.42	24.63		
205	17.78	34.84	25.22		
304	11.96	34.23	26.02		
409	08.21	34.13	26.58		
509	06.50	34.19	26.87		
610	05.86	34.30	27.04		
808	04.76	34.45	27.29		
1009	04.03	34.46	27.38		
1208	03.55	34.52	27.47		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.11	35.30	24.14	0.000	1.742
10	23.11	35.31	24.15	0.038	1.704
20	23.10	35.29	24.14	0.076	1.666
30	23.08	35.30	24.15	0.113	1.629
50	22.98	35.36	24.23	0.188	1.554
75	22.28	35.41	24.46	0.279	1.463
100	21.80	35.42	24.61	0.365	1.377
150	20.48	35.26	24.85	0.528	1.214
200	18.00	34.87	25.19	0.678	1.064
250	15.20	34.53	25.58	0.812	0.930
300	12.17	34.24	25.98	0.926	0.816
400	08.45	34.13	26.54	1.110	0.632
500	06.62	34.18	26.84	1.253	0.489
600	05.91	34.29	27.02	1.373	0.369
700	05.37	34.39	27.17	1.478	0.264
800	04.80	34.44	27.27	1.572	0.170
1000	04.08	34.46	27.37	1.742	0.000

STATION 39

M/V Hugh M. Smith: Cruise 20, 21°03'N, 158°36'W, March 26, 1953. Messenger time: 0340 GCT. Weather: 02, cloud coverage 1. Wind: 090°, 15 kt. Sea: 3-5 ft. Wire angle: 38°. Depth of water: 1500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.90	35.10	23.78		
08	23.88	35.13	23.80		
20	23.90	35.15	23.81		
43	23.76	35.20	23.88		
81	21.81	35.32	24.53		
152	19.52	35.11	24.99		
220	16.05	34.71	25.53		
220	15.80	34.71	25.59		
290	11.24	34.34	26.24		
357	09.21	34.23	26.50		
426	07.36	34.17	26.73		
559	06.24	34.30	26.99		
692	05.36	34.37	27.16		
822	04.70	34.49	27.33		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.87	35.10	23.77	0.000	1.685
10	23.88	35.13	23.79	0.041	1.644
20	23.90	35.15	23.80	0.082	1.603
30	23.86	35.17	23.83	0.123	1.562
50	23.60	35.22	23.94	0.204	1.481
75	22.10	35.32	24.45	0.298	1.387
100	21.03	35.27	24.71	0.383	1.302
150	19.60	35.12	24.97	0.541	1.144
200	17.33	34.86	25.34	0.685	1.000
250	13.44	34.49	25.92	0.806	0.879
300	10.97	34.33	26.27	0.905	0.780
400	07.92	34.18	26.66	1.069	0.616
500	06.67	34.25	26.89	1.203	0.482
600	05.99	34.32	27.03	1.321	0.364
700	05.32	34.38	27.16	1.426	0.259
800	04.80	34.46	27.29	1.519	0.166
1000	04.13	34.50	27.39	1.685	0.000

STATION 40

M/V Hugh M. Smith: Cruise 20, 20°35'N, 158°02'W, March 26, 1953. Messenger time: 1139 GCT. Weather: 02, cloud coverage 1. Wind: 060°, 18 kt. Sea: 5-8 ft. Wire angle: 15°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.20	34.88	23.50		
10	24.22	34.86	23.49		
30	23.79	35.15	23.84		
58	23.34	35.30	24.08		
114	21.02	35.19	24.65		
223	13.92	34.42	25.77		
331	09.30	34.19	26.45		
435	07.38	34.14	26.71		
543	06.15	34.26	26.97		
649	05.39	34.35	27.14		
864	04.56	34.47	27.33		
1073	03.86	34.49	27.42		
1277	03.40	34.53	27.49		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.23	34.88	23.50	0.000	1.687
10	24.22	34.86	23.49	0.044	1.643
20	24.11	34.95	23.59	0.088	1.599
30	23.79	35.15	23.83	0.130	1.557
50	23.57	35.26	23.98	0.210	1.477
75	22.80	35.35	24.27	0.306	1.881
100	21.80	35.28	24.50	0.395	1.292
150	19.01	34.95	24.99	0.557	1.130
200	15.66	34.58	25.52	0.696	0.991
250	12.24	34.32	26.03	0.810	0.877
300	10.32	34.23	26.31	0.906	0.781
400	07.92	34.14	26.63	1.069	0.618
500	06.60	34.21	26.87	1.206	0.481
600	05.69	34.31	27.06	1.323	0.364
700	05.18	34.38	27.18	1.426	0.261
800	04.78	34.44	27.27	1.519	0.168
1000	04.06	34.48	27.38	1.687	0.000

STATION 41

M/V Hugh M. Smith: Cruise 20, 20°08'N, 157°32'W, March 26, 1953. Messenger time: 1827 GCT. Weather: 02, cloud coverage 5. Wind: 060° 21 kt. Sea: 5-8 ft. Wire angle: 20°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.20	34.83	23.49		
09	24.16	34.88	23.52		
28	24.18	34.84	23.49		
56	24.02	34.92	23.60		
111	22.66	35.42	24.37		
222	16.36	34.66	25.42		
333	10.17	34.17	26.30		
440	07.70	34.16	26.68		
551	06.27	34.15	26.87		
659	05.47	34.36	27.13		
880	04.53	34.46	27.32		
1095	03.93	34.53	27.44		
1304	03.36	34.59	27.54		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.16	34.83	23.48	0.000	1.824
10	24.16	34.88	23.52	0.044	1.780
20	24.17	34.85	23.49	0.088	1.736
30	24.17	34.84	23.49	0.132	1.692
50	24.07	34.89	23.55	0.220	1.604
75	23.79	35.02	23.73	0.327	1.497
100	23.27	35.38	24.16	0.427	1.397
150	21.62	35.34	24.60	0.607	1.217
200	18.10	34.87	25.16	0.764	1.060
250	14.65	34.49	25.67	0.895	0.929
300	11.80	34.25	26.06	1.006	0.818
400	08.52	34.16	26.55	1.185	0.639
500	06.85	34.15	26.79	1.330	0.494
600	05.90	34.26	27.00	1.454	0.370
700	05.26	34.38	27.17	1.560	0.264
800	04.84	34.43	27.26	1.655	0.169
1000	04.20	34.50	27.38	1.824	0.000

STATION 42

M/V Hugh M. Smith: Cruise 20, 19°36'N, 156°58'W, March 27, 1953. Messenger time: first cast 0136 GCT, second cast 0155 GCT. Weather: 02, cloud coverage 2. Wind: 040°, 4 kt. Sea: 3-5 ft. Wire angle: first cast 12°, second cast 12°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.10	35.01	23.63		
09	23.92	34.96	23.66		
23	23.88	34.98	23.68		
52	23.87	34.98	23.69		
103	23.31	35.23	24.04		
199	16.83	34.73	25.36		
290	10.76	34.15	26.18		
390	07.98	34.05	26.55		
488	06.69	34.20	26.85		
585	05.66	34.33	27.09		
777	04.98	34.38	27.21		
973	04.29	34.49	27.37		
1166	03.56	34.52	27.47		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D 1000 - \Delta D$ (dyn. m)
00	24.14	35.01	23.62	0.000	1.762
10	23.92	34.96	23.65	0.043	1.719
20	23.90	34.98	23.67	0.085	1.677
30	23.88	34.98	23.68	0.127	1.635
50	23.87	34.98	23.68	0.212	1.550
75	23.90	35.06	23.73	0.318	1.444
100	23.39	35.23	24.01	0.419	1.343
150	20.45	35.14	24.76	0.599	1.163
200	16.80	34.73	25.37	0.747	1.015
250	12.94	34.33	25.90	0.868	0.894
300	10.39	34.14	26.23	0.969	0.793
400	07.80	34.06	26.58	1.138	0.624
500	06.55	34.22	26.88	1.276	0.486
600	05.58	34.34	27.10	1.391	0.371
700	05.18	34.36	27.16	1.492	0.270
800	04.89	34.39	27.22	1.589	0.173
1000	04.20	34.50	27.38	1.762	0.000

STATION 43

M/V Hugh M. Smith: Cruise 20, 19°13'N, 156°31'W, March 27, 1953. Messenger time: 0742 GCT. Weather: 02, cloud coverage 3. Wind: 130°, 12 kt. Sea: 1-3 ft. Wire angle: 18°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.20	34.90	23.52		
09	24.10	34.99	23.62		
24	24.00	35.00	23.66		
51	23.68	35.07	23.81		
101	22.22	35.17	24.30		
198	17.36	34.77	25.27		
295	11.31	34.22	26.13		
396	08.30	34.22	26.64		
493	06.73	34.21	26.86		
590	05.74	34.26	27.02		
784	05.00	34.43	27.25		
981	04.22	34.50	27.39		
1172	03.69	34.52	27.46		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.24	34.90	23.51	0.000	1.748
10	24.09	34.99	23.62	0.043	1.705
20	24.04	35.00	23.65	0.086	1.662
30	23.95	35.01	23.68	0.128	1.620
50	23.73	35.06	23.78	0.212	1.536
75	23.05	35.15	24.05	0.313	1.435
100	22.25	35.17	24.29	0.407	1.341
150	19.90	35.03	24.83	0.579	1.169
200	17.18	34.75	25.29	0.727	1.021
250	12.97	34.33	25.89	0.850	0.898
300	11.18	34.22	26.15	0.953	0.795
400	08.22	34.22	26.64	1.123	0.625
500	06.65	34.22	26.87	1.260	0.488
600	05.68	34.26	27.02	1.378	0.370
700	05.26	34.37	27.16	1.483	0.265
800	04.95	34.44	27.25	1.578	0.170
1000	04.19	34.50	27.39	1.748	0.000

STATION 44

M/V Hugh M. Smith: Cruise 20, 18°50'N, 156°02'W, March 27, 1953. Messenger time: 1513 GCT. Weather: 00, cloud coverage 1, Wind: 080°, 22 kt. Sea: 3-5 ft. Wire angle: 32°. Depth of water: 1400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.70	34.59	23.45		
09	23.66	34.56	23.43		
26	23.68	34.63	23.48		
50	23.67	34.61	23.47		
99	23.72	34.53	23.39		
195	18.98	34.99	25.03		
290	12.50	34.23	25.92		
384	08.20	34.12	26.57		
481	06.80	34.20	26.84		
575	06.10	34.25	26.97		
769	05.18	34.41	27.21		
958	04.44	34.44	27.32		
1141	03.72	34.50	27.44		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.66	34.59	23.45	0.000	1.874
10	23.66	34.56	23.42	0.045	1.829
20	23.67	34.61	23.46	0.089	1.785
30	23.68	34.63	23.47	0.133	1.741
50	23.67	34.61	23.46	0.222	1.652
75	23.70	34.57	23.42	0.334	1.540
100	23.72	34.53	23.38	0.447	1.427
150	20.98	35.12	24.61	0.645	1.229
200	18.73	34.96	25.07	0.804	1.070
250	14.80	34.49	25.64	0.939	0.935
300	11.98	34.20	25.99	1.052	0.822
400	07.90	34.13	26.62	1.231	0.643
500	06.64	34.21	26.86	1.369	0.505
600	05.98	34.26	26.99	1.490	0.384
700	05.47	34.36	27.13	1.599	0.275
800	05.05	34.42	27.23	1.697	0.177
1000	04.28	34.45	27.34	1.874	0.000

STATION 45

M/V Hugh M. Smith: Cruise 20, 17°45'N, 155°27'W, March 28, 1953. Messenger time: 0150 GCT. Weather: 16, cloud coverage 2. Wind: 080°, 22 kt. Sea: 8-12 ft. Wire angle: 18°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.60	34.54	23.43		
11	23.61	34.50	23.40		
29	23.60	34.53	23.43		
58	23.58	34.62	23.50		
115	23.02	35.24	24.13		
227	18.54	34.98	25.14		
337	10.04	34.29	26.41		
444	09.26	34.33	26.57		
444	08.86	34.33	26.64		
556	07.16	34.43	26.97		
664	06.20	34.48	27.14		
887	05.04	34.50	27.30		
1101	04.20	34.53	27.41		
1309	03.58	34.59	27.52		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.62	34.54	23.42	0.000	1.848
10	23.61	34.50	23.39	0.045	1.803
20	23.61	34.51	23.40	0.090	1.758
30	23.60	34.53	23.42	0.135	1.713
50	23.59	34.59	23.47	0.224	1.624
75	23.68	34.78	23.59	0.334	1.514
100	23.32	35.17	23.99	0.437	1.411
150	20.86	35.17	24.68	0.620	1.228
200	19.51	35.07	24.96	0.780	1.068
250	16.00	34.72	25.55	0.919	0.929
300	11.75	34.34	26.14	1.031	0.817
400	09.38	34.32	26.54	1.203	0.645
500	08.15	34.38	26.78	1.351	0.497
600	06.72	34.46	27.05	1.471	0.377
700	06.00	34.49	27.17	1.576	0.272
800	05.45	34.50	27.24	1.672	0.176
1000	04.62	34.52	27.35	1.848	0.000

STATION 46

M/V Hugh M. Smith: Cruise 20, 18°04'N, 156°04'W, March 28, 1953. Messenger time: 0813 GCT. Weather: 03, cloud coverage 3. Wind: 080°, 26 kt. Sea: 8-12 ft. Wire angle: 33°. Depth of water 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.50	34.52	23.46		
09	23.44	34.51	23.46		
25	23.46	34.54	23.48		
50	23.46	34.58	23.51		
104	23.40	35.16	23.96		
201	18.75	35.02	25.12		
299	11.08	34.22	26.17		
299	11.21	34.22	26.15		
393	10.18	34.42	26.49		
491	08.32	34.42	26.79		
585	06.96	34.40	26.98		
776	05.46	34.46	27.21		
797	-	-	-		
960	04.47	34.48	27.34		
1137	04.07	34.51	27.41		
1137	04.43	34.51	27.37		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.46	34.52	23.45	0.000	1.852
10	23.44	34.51	23.45	0.044	1.808
20	23.45	34.53	23.46	0.089	1.763
30	23.46	34.55	23.48	0.133	1.719
50	23.46	34.58	23.50	0.221	1.631
75	23.50	34.85	23.69	0.330	1.522
100	23.44	35.05	23.86	0.434	1.418
150	20.70	35.14	24.70	0.618	1.234
200	18.81	35.02	25.10	0.775	1.077
250	15.22	34.68	25.69	0.907	0.945
300	11.12	34.22	26.16	1.015	0.837
400	10.05	34.42	26.51	1.192	0.660
500	08.21	34.42	26.80	1.340	0.512
600	06.82	34.40	26.99	1.465	0.387
700	06.04	34.44	27.12	1.575	0.277
800	05.38	34.46	27.22	1.675	0.177
1000	04.40	34.49	27.36	1.852	0.000

STATION 47

M/V Hugh M. Smith: Cruise 20, 18°34'N, 156°40'W, March 28, 1953. Messenger time: 1522 GCT. Weather: 02, cloud coverage 1. Wind: 080°, 25 kt. Sea: 5-8 ft. Wire angle: 42°. Depth of water: 2000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.50	34.42	23.37		
08	23.51	34.41	23.36		
22	23.53	34.40	23.35		
45	23.54	34.42	23.36		
88	23.55	34.41	23.35		
168	18.88	34.91	25.00		
246	12.84	34.21	25.83		
324	09.72	34.33	26.50		
404	08.86	34.37	26.66		
481	07.72	34.36	26.83		
640	06.25	34.39	27.06		
799	05.40	34.45	27.21		
965	04.62	34.46	27.31		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.52	34.42	23.36	0.000	1.810
10	23.52	34.41	23.35	0.045	1.765
20	23.52	34.40	23.34	0.091	1.719
30	23.53	34.41	23.35	0.136	1.674
50	23.54	34.42	23.35	0.227	1.583
75	23.55	34.41	23.34	0.341	1.469
100	23.33	35.10	23.93	0.449	1.361
150	19.82	35.01	24.83	0.628	1.182
200	18.05	34.89	25.19	0.779	1.031
250	12.34	34.21	25.93	0.904	0.906
300	10.30	34.30	26.37	1.001	0.809
400	08.93	34.37	26.65	1.160	0.650
500	07.52	34.36	26.86	1.298	0.512
600	06.55	34.38	27.01	1.419	0.391
700	05.92	34.41	27.11	1.528	0.282
800	05.40	34.45	27.21	1.628	0.182
1000	04.46	34.46	27.32	1.810	0.000

STATION 48

M/V Hugh M. Smith: Cruise 20, 18°59'N, 157°06'W, March 28, 1953. Messenger time: 2206 GCT. Weather: 02, cloud coverage 1. Wind: 100°, 25 kt. Sea: 5-8 ft. Wire angle: 35°. Depth of water: 2100 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.00	35.01	23.68		
09	23.93	34.91	23.62		
25	23.94	34.95	23.64		
51	23.94	34.93	23.63		
98	23.72	35.10	23.82		
191	19.22	34.96	24.95		
282	12.67	34.22	25.87		
372	08.91	34.09	26.44		
468	07.56	34.21	26.74		
561	06.58	34.28	26.93		
755	05.30	34.40	27.19		
951	04.34	34.45	27.33		
1151	03.74	34.46	27.40		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	23.96	35.01	23.68	0.000	1.872
10	23.93	34.91	23.61	0.043	1.829
20	23.94	34.94	23.63	0.085	1.787
30	23.94	34.95	23.64	0.128	1.744
50	23.94	34.93	23.62	0.214	1.658
75	23.88	35.02	23.71	0.320	1.552
100	23.68	35.10	23.83	0.425	1.447
150	22.33	35.15	24.25	0.621	1.251
200	18.55	34.89	25.06	0.788	1.084
250	14.64	34.42	25.62	0.923	0.949
300	11.60	34.16	26.03	1.036	0.836
400	08.41	34.10	26.52	1.218	0.654
500	07.20	34.24	26.81	1.364	0.508
600	06.26	34.30	26.98	1.488	0.384
700	05.60	34.38	27.13	1.597	0.275
800	05.07	34.42	27.22	1.695	0.177
1000	04.18	34.45	27.35	1.872	0.000

STATION 49

M/V Hugh M. Smith: Cruise 20, 19°26'N, 157°38'W, March 29, 1953. Messenger time: 0424 GCT. Weather: 16, cloud coverage 4. Wind: 340°, 13 kt. and variable. Sea: < 1 ft. Wire angle: 00°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.50	34.68	23.27		
10	24.38	34.59	23.24		
30	24.24	34.61	23.30		
61	24.34	34.85	23.45		
120	23.26	35.10	23.96		
234	16.35	34.60	25.38		
347	09.82	34.08	26.28		
457	07.54	34.12	26.67		
570	06.10	34.21	26.94		
682	05.35	34.30	27.10		
907	04.36	34.43	27.32		
1124	03.72	34.44	27.39		
1338	03.23	34.50	27.49		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.50	34.68	23.27	0.000	1.915
10	24.38	34.59	23.23	0.046	1.869
20	24.29	34.60	23.27	0.093	1.822
30	24.24	34.61	23.29	0.139	1.776
50	24.28	34.76	23.39	0.230	1.685
75	24.35	34.94	23.51	0.342	1.573
100	23.82	35.04	23.74	0.449	1.466
150	21.59	35.09	24.42	0.644	1.271
200	19.20	34.89	24.90	0.811	1.104
250	15.00	34.45	25.56	0.952	0.963
300	12.12	34.17	25.94	1.068	0.847
400	08.61	34.09	26.48	1.256	0.659
500	06.94	34.14	26.77	1.405	0.510
600	05.87	34.23	26.98	1.531	0.384
700	05.27	34.31	27.11	1.641	0.274
800	04.80	34.39	27.23	1.739	0.176
1000	04.04	34.43	27.35	1.915	0.000

STATION 50

M/V Hugh M. Smith: Cruise 20, 19°54'N, 158°08'W, March 29, 1953. Messenger time: 1039 GCT. Weather: 01, cloud coverage 4. Wind: 080°, 6 kt. Sea: < 1 ft. Wire angle: 06°. Depth of water: 2000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.40	34.79	23.38		
10	24.42	34.79	23.38		
25	24.39	34.78	23.38		
49	24.28	35.11	23.66		
98	22.28	35.28	24.37		
198	17.24	34.80	25.32		
294	11.67	34.23	26.07		
395	08.43	34.16	26.57		
491	06.92	34.20	26.82		
592	05.88	34.29	27.03		
792	04.96	34.42	27.24		
986	04.21	34.51	27.40		
1190	03.68	34.51	27.45		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.40	34.79	23.38	0.000	1.766
10	24.42	34.79	23.37	0.045	1.721
20	24.40	34.78	23.37	0.090	1.676
30	24.38	34.80	23.39	0.135	1.631
50	24.27	35.11	23.66	0.223	1.543
75	23.43	35.21	23.98	0.326	1.440
100	22.10	35.28	24.42	0.420	1.346
150	19.28	35.02	24.98	0.584	1.182
200	17.05	34.78	25.35	0.728	1.038
250	13.50	34.39	25.83	0.851	0.915
300	11.50	34.22	26.09	0.957	0.809
400	08.32	34.16	26.58	1.133	0.633
500	06.82	34.20	26.83	1.274	0.492
600	05.83	34.29	27.03	1.395	0.371
700	05.33	34.37	27.15	1.500	0.266
800	04.91	34.42	27.24	1.596	0.170
1000	04.18	34.51	27.39	1.766	0.000

STATION 51

M/V Hugh M. Smith: Cruise 20, 20°22'N, 158°38'W, March 29, 1953. Messenger time: 1708 GCT. Weather: 01, cloud coverage 3. Wind: 080°, 18 kt. Sea: 3-5 ft. Wire angle: 15°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.70	35.21	23.92		
10	23.68	35.21	23.92		
24	23.68	35.22	23.92		
52	23.64	35.23	23.94		
103	21.26	35.16	24.56		
204	15.47	34.57	25.56		
304	11.71	34.22	26.06		
409	08.82	34.14	26.49		
510	06.21	34.23	26.94		
611	05.58	34.33	27.10		
811	04.75	34.43	27.27		
1014	04.05	34.51	27.41		
1213	03.57	34.56	27.50		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.68	35.21	23.91	0.000	1.718
10	23.68	35.21	23.91	0.040	1.678
20	23.68	35.22	23.92	0.080	1.638
30	23.68	35.22	23.92	0.120	1.598
50	23.64	35.23	23.94	0.200	1.518
75	22.10	35.23	24.38	0.295	1.423
100	21.32	35.16	24.54	0.382	1.336
150	19.02	34.94	24.98	0.544	1.174
200	15.70	34.59	25.51	0.683	1.035
250	13.40	34.36	25.83	0.802	0.916
300	11.82	34.23	26.04	0.909	0.809
400	09.10	34.14	26.44	1.095	0.623
500	06.40	34.22	26.90	1.239	0.479
600	05.63	34.32	27.08	1.354	0.364
700	05.19	34.38	27.18	1.456	0.262
800	04.80	34.42	27.26	1.550	0.168
1000	04.09	34.50	27.40	1.718	0.000

STATION 52

M/V Hugh M. Smith: Cruise 20, 20°42'N, 159°15'W, March 30, 1953. Messenger time: 0022 GCT. Weather: 02, cloud coverage 3. Wind: 110°, 04 kt. Sea: < 1 ft. Wire angle: 06°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
05	24.06	35.16	23.76		
15	23.74	35.22	23.91		
29	23.69	35.19	23.90		
54	22.72	35.33	24.28		
101	22.26	35.27	24.37		
200	18.26	34.88	25.13		
295	12.30	34.32	26.02		
394	08.68	34.13	26.51		
489	06.86	34.20	26.83		
589	05.93	34.26	27.00		
785	04.89	34.45	27.28		
977	04.16	34.59 1/	27.46		
1178	03.64	34.52	27.46		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.30	35.16	23.69	0.000	1.760
10	23.85	35.20	23.85	0.041	1.719
20	23.69	35.21	23.91	0.082	1.678
30	23.69	35.19	23.89	0.122	1.638
50	22.80	35.33	24.26	0.199	1.561
75	22.51	35.31	24.32	0.291	1.469
100	22.30	35.27	24.35	0.381	1.379
150	21.39	35.18	24.54	0.558	1.202
200	18.25	34.88	25.13	0.717	1.043
250	14.42	34.51	25.73	0.848	0.912
300	12.09	34.30	26.04	0.957	0.803
400	08.53	34.13	26.53	1.139	0.621
500	06.74	34.21	26.85	1.282	0.478
600	05.85	34.27	27.01	1.402	0.358
700	05.24	34.38	27.17	1.508	0.252
800	04.82	34.46	27.28	1.601	0.159
1000	04.06	34.58	27.46	1.760	0.000

1/ Doubtful salinity value.

STATION 53

M/V Hugh M. Smith: Cruise 20, 21°16'N, 159°44'W, March 30, 1953. Messenger time: 0645 GCT. Weather: 02, cloud coverage 2. Wind: 080°, 8 kt. Sea: < 1 ft. Wire angle: 02°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.80	35.27	23.93		
10	23.62	35.32	24.02		
25	23.17	35.34	24.16		
51	22.81	35.36	24.28		
100	21.82	35.38	24.58		
201	18.86	35.08	25.13		
295	13.10	34.34	25.88		
395	09.47	34.14	26.39		
490	07.49	34.22	26.76		
591	06.30	34.25	26.94		
788	04.99	34.39	27.22		
982	04.22	34.45	27.35		
1185	03.58	34.52	27.47		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	23.80	35.27	23.92	0.000	1.798
10	23.62	35.32	24.01	0.039	1.759
20	23.22	35.33	24.14	0.078	1.720
30	23.05	35.35	24.20	0.116	1.682
50	22.82	35.36	24.27	0.190	1.608
75	22.50	35.37	24.37	0.281	1.517
100	21.82	35.38	24.57	0.368	1.430
150	20.79	35.32	24.81	0.533	1.265
200	18.90	35.08	25.12	0.686	1.112
250	15.25	34.59	25.61	0.820	0.978
300	12.90	34.32	25.90	0.936	0.862
400	09.32	34.14	26.41	1.130	0.668
500	07.35	34.22	26.77	1.283	0.515
600	06.23	34.24	26.94	1.411	0.387
700	05.43	34.33	27.11	1.523	0.275
800	04.90	34.39	27.22	1.622	0.176
1000	04.19	34.46	27.35	1.798	0.000

STATION 54

M/V Hugh M. Smith: Cruise 20, 21°44'N, 160°17'W, March 30, 1953. Messenger time: 1300 GCT. Weather: 02, cloud coverage 1. Wind: 080°, 8 kt. Sea: < 1 ft. Wire angle: 11°. Depth of water: 700 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.40	35.33	24.10		
10	23.36	35.33	24.10		
24	23.30	35.40	24.17		
49	23.24	35.30	24.11		
96	22.88	35.40	24.29		
193	20.59	35.26	24.82		
285	14.79	34.57	25.71		
381	09.94	34.21	26.37		
474	07.10	34.18	26.78		
572	06.46	34.13	26.83		
763	05.14	34.33	27.15		
954	04.32	34.52	27.38		
1151	03.62	34.55	27.49		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.36	35.33	24.09	0.000	1.865
10	23.36	35.33	24.09	0.038	1.827
20	23.33	35.38	24.14	0.076	1.789
30	23.29	35.39	24.16	0.114	1.751
50	23.23	35.30	24.11	0.190	1.675
75	23.09	35.34	24.18	0.285	1.580
100	22.81	35.40	24.31	0.378	1.487
150	21.70	35.36	24.59	0.555	1.310
200	20.26	35.23	24.88	0.719	1.146
250	18.00	34.96	25.26	0.867	0.998
300	13.90	34.48	25.82	0.994	0.871
400	09.20	34.20	26.48	1.189	0.676
500	06.83	34.16	26.80	1.337	0.528
600	06.28	34.13	26.85	1.468	0.397
700	05.59	34.21	27.00	1.590	0.275
800	04.95	34.39	27.21	1.695	0.170
1000	04.15	34.54	27.42	1.865	0.000

STATION 54A

M/V Hugh M. Smith: Cruise 20, 22°09'N, 160°59'W, March 31, 1953. Messenger time: 0742 GCT. Weather: 02, cloud coverage 2. Wind: calm. Sea: < 1 ft. Wire angle: 21°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.50	35.24	23.70		
10	23.84	35.21	23.87		
24	23.68	35.25	23.95		
46	23.57	35.26	23.99		
92	22.24	35.37	24.45		
185	16.96	34.74	25.34		
273	12.60	34.29	25.94		
364	09.82	34.11	26.31		
453	07.72	34.11	26.64		
548	06.04	34.15	26.90		
734	04.80	34.36	27.21		
918	04.34	34.43	27.32		
1116	03.74	34.44	27.39		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.47	35.24	23.70	0.000	1.746
10	23.84	35.21	23.86	0.041	1.705
20	23.71	35.24	23.92	0.081	1.665
30	23.63	35.25	23.96	0.121	1.625
50	23.52	35.27	24.00	0.200	1.546
75	22.70	35.35	24.30	0.295	1.451
100	22.00	35.36	24.51	0.384	1.362
150	19.80	35.11	24.91	0.548	1.198
200	15.88	34.62	25.50	0.690	1.056
250	13.30	34.35	25.84	0.809	0.937
300	11.74	34.22	26.05	0.916	0.830
400	08.88	34.11	26.46	1.100	0.646
500	06.80	34.12	26.77	1.250	0.496
600	05.57	34.22	27.01	1.375	0.371
700	04.97	34.33	27.16	1.480	0.266
800	04.60	34.40	27.26	1.574	0.172
1000	04.12	34.44	27.35	1.746	0.000

STATION 55A

M/V Hugh M. Smith: Cruise 20, 21°48'N, 161°30'W, March 31, 1953. Messenger time: 1407 GCT. Weather: 02, cloud coverage 2. Wind: 040°, 6 kt. Sea: < 1 ft. Wire angle: 06°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.30	35.11	23.66		
11	24.26	35.16	23.71		
26	24.10	35.15	23.74		
50	24.04	35.15	23.76		
98	23.72 1/	35.29	23.96		
198	18.70	34.98	25.10		
292	11.68	34.24	26.08		
393	08.90	34.11	26.46		
489	07.00	34.07	26.71		
589	05.89	34.15	26.92		
786	04.92	34.38	27.22		
979	04.24	34.45	27.35		
1181	03.62	34.50	27.45		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.28	35.11	23.66	0.000	1.852
10	24.26	35.16	23.70	0.042	1.810
20	24.16	35.15	23.72	0.084	1.768
30	24.06	35.15	23.75	0.126	1.726
50	24.04	35.15	23.76	0.209	1.643
75	23.88	35.24	23.87	0.312	1.540
100	23.67	35.29	23.97	0.413	1.439
150	21.68	35.31	24.56	0.598	1.254
200	18.55	34.97	25.13	0.757	1.095
250	15.42	34.62	25.60	0.891	0.961
300	11.41	34.23	26.12	1.002	0.850
400	08.73	34.10	26.47	1.182	0.670
500	06.82	34.07	26.73	1.334	0.518
600	05.82	34.15	26.92	1.464	0.388
700	05.30	34.30	27.10	1.577	0.275
800	04.85	34.39	27.23	1.676	0.176
1000	04.19	34.46	27.35	1.852	0.000

1/ Temperature doubtful, BT indicates 22.2°C.

STATION 55

M/V Hugh M. Smith: Cruise 20, 21°22'N, 160°56'W, March 31, 1953. Messenger time: 2037 GCT. Weather: 02, cloud coverage 2. Wind: 080°, 14 kt. Sea: 3-5 ft. Wire angle: 07°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.20	35.18	23.73		
10	24.22	35.19	23.74		
26	24.00	35.21	23.82		
55	23.71	35.28	23.96		
109	22.36	35.34	24.39		
215	18.59	35.09	25.21		
319	11.66	34.30	26.13		
427	08.00	34.19	26.66		
532	06.32	34.23	26.93		
636	05.50	34.24	27.04		
842	04.60	34.55 1/	27.38		
1051	04.00	34.46 1/	27.38		
1253	03.40	34.60	27.55		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.24	35.18	23.72	0.000	1.795
10	24.22	35.19	23.74	0.042	1.753
20	24.08	35.20	23.78	0.083	1.712
30	23.95	35.22	23.84	0.124	1.671
50	23.78	35.27	23.93	0.205	1.590
75	23.25	35.33	24.13	0.303	1.492
100	22.62	35.34	24.32	0.396	1.399
150	21.01	35.29	24.73	0.570	1.225
200	19.20	35.14	25.09	0.725	1.070
250	16.45	34.84	25.53	0.862	0.933
300	12.88	34.41	25.97	0.978	0.817
400	08.70	34.19	26.55	1.162	0.633
500	06.72	34.22	26.86	1.304	0.491
600	05.74	34.24	27.00	1.424	0.371
700	05.19	34.29	27.11	1.533	0.262
800	04.75	34.42	27.26	1.630	0.165
1000	04.13	34.54	27.42	1.795	0.000

1/ Possible transposition of values.

STATION 56

M/V Hugh M. Smith: Cruise 20, 21°00'N, 160°25'W, April 1, 1953. Messenger time: 0235 GCT. Weather: 02, cloud coverage 6. Wind: 050°, 12 kt. Sea: 3-5 ft. Wire angle: 08°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.60	35.02	23.50		
10	24.56	35.03	23.52		
25	24.29	35.09	23.65		
54	23.68	35.24	23.94		
107	22.05	35.24	24.40		
212	17.64	34.85	25.26		
316	11.38	34.21	26.11		
425	08.35	34.14	26.57		
530	06.70	34.19	26.84		
634	05.80	34.30	27.05		
840	04.74	34.41	27.26		
1050	03.96	34.52	27.43		
1251	03.40	34.51	27.48		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.58	35.02	23.50	0.000	1.815
10	24.56	35.03	23.51	0.044	1.771
20	24.40	35.07	23.59	0.087	1.728
30	24.20	35.12	23.69	0.130	1.685
50	23.79	35.23	23.89	0.213	1.602
75	23.15	35.27	24.11	0.311	1.504
100	22.30	35.25	24.34	0.404	1.411
150	20.44	35.13	24.76	0.576	1.239
200	18.40	34.93	25.13	0.730	1.085
250	15.02	34.55	25.63	0.863	0.952
300	12.03	34.26	26.02	0.976	0.839
400	08.94	34.14	26.47	1.161	0.654
500	07.10	34.17	26.77	1.311	0.504
600	06.03	34.27	26.99	1.436	0.379
700	05.40	34.34	27.12	1.545	0.270
800	04.90	34.39	27.22	1.644	0.171
1000	04.10	34.51	27.40	1.815	0.000

STATION 57

M/V Hugh M. Smith: Cruise 20, 20°31'N, 159°56'W, April 1, 1953. Messenger time: 0834 GCT. Weather: 02, cloud coverage 7. Wind: 080°, 11 kt. Sea: 1-3 ft. Wire angle: 05°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.40	34.81	23.41		
10	24.36	34.78	23.39		
25	24.32	34.83	23.44		
54	24.34	35.10	23.64		
109	23.20	35.32	24.14		
215	17.54	34.86	25.29		
321	11.28	34.22	26.14		
429	08.48	34.14	26.54		
534	06.62	34.22	26.88		
643	05.60	34.35	27.11		
852	04.61	34.47	27.32		
1064	03.96	34.59	27.49		
1267	03.42	34.55	27.51		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.36	34.81	23.41	0.000	1.832
10	24.36	34.78	23.38	0.045	1.787
20	24.34	34.80	23.41	0.090	1.742
30	24.34	34.97	23.53	0.134	1.698
50	24.36	35.08	23.61	0.221	1.611
75	23.92	35.25	23.87	0.326	1.506
100	23.52	35.31	24.03	0.426	1.406
150	21.50	35.26	24.57	0.609	1.223
200	18.65	34.98	25.11	0.768	1.064
250	14.37	34.51	25.74	0.899	0.933
300	11.90	34.27	26.06	1.008	0.824
400	09.17	34.14	26.43	1.194	0.638
500	07.18	34.19	26.77	1.345	0.487
600	05.97	34.30	27.02	1.469	0.363
700	05.30	34.38	27.17	1.574	0.258
800	04.83	34.44	27.27	1.669	0.163
1000	04.13	34.56	27.44	1.832	0.000

STATION 58

M/V Hugh M. Smith: Cruise 20, 20°02'N, 159°22'W, April 1, 1953. Messenger time: 1508 GCT. Weather: 02, cloud coverage 10. Wind: 080°, 18 kt. Sea: 1-3 ft. Wire angle: 17°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.20	34.69	23.38		
10	24.15	34.68	23.38		
24	24.18	34.67	23.36		
48	24.14	34.73	23.42		
95	24.06	35.21	23.80		
188	20.34	35.13	24.79		
277	14.43	34.43	25.67		
370	09.84	34.14	26.33		
459	07.76	34.19	26.69		
552	06.36	34.25	26.93		
736	05.08	34.38	27.20		
918	04.43	34.50	27.36		
1107	03.78	34.46	27.40		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.17	34.69	23.37	0.000	1.896
10	24.15	34.68	23.37	0.045	1.851
20	24.16	34.67	23.36	0.090	1.806
30	24.18	34.68	23.36	0.136	1.760
50	24.14	34.74	23.42	0.226	1.670
75	24.47	35.04	23.55	0.337	1.559
100	23.90	35.24	23.87	0.442	1.454
150	22.10	35.26	24.40	0.634	1.262
200	18.85	34.98	25.06	0.798	1.098
250	16.05	34.62	25.46	0.938	0.958
300	13.18	34.30	25.83	1.059	0.837
400	09.01	34.15	26.47	1.254	0.642
500	07.10	34.22	26.81	1.402	0.494
600	05.91	34.28	27.01	1.525	0.371
700	05.22	34.36	27.16	1.631	0.265
800	04.87	34.42	27.25	1.726	0.170
1000	04.15	34.50	27.39	1.896	0.000

STATION 59

M/V Hugh M. Smith: Cruise 20, 19°36'N, 158°52'W, April 1, 1953. Messenger time: 2105 GCT. Weather: 01, cloud coverage 4. Wind: 080°, 16 kt. Sea: 3-5 ft. Wire angle: 25°. Depth of water: 1900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.40	34.90	23.45		
09	24.43	34.89	23.45		
23	24.43	34.88	23.44		
49	24.38	35.07	23.60		
96	23.78	35.28	23.94		
188	19.79	35.11	24.92		
279	14.11	34.46	25.76		
279	14.01	34.46	25.78		
376	09.14	34.18	26.47		
470	07.40	34.20	26.75		
565	06.39	34.29	26.96		
752	05.10	34.40	27.21		
943	04.36	34.52	27.39		
1132	03.84	34.55	27.47		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.44	34.90	23.45	0.000	1.853
10	24.43	34.89	23.45	0.044	1.809
20	24.43	34.88	23.44	0.089	1.764
30	24.42	34.90	23.46	0.133	1.720
50	24.36	35.08	23.61	0.221	1.632
75	24.01	35.24	23.84	0.326	1.527
100	23.70	35.29	23.96	0.427	1.426
150	21.65	35.25	24.52	0.614	1.239
200	19.06	35.04	25.05	0.775	1.078
250	15.80	34.65	25.54	0.913	0.940
300	12.96	34.37	25.93	1.030	0.823
400	08.56	34.18	26.56	1.215	0.638
500	07.05	34.22	26.81	1.359	0.494
600	06.11	34.31	27.01	1.481	0.372
700	05.42	34.37	27.14	1.588	0.265
800	04.92	34.43	27.25	1.684	0.169
1000	04.19	34.53	27.41	1.853	0.000

STATION 60

M/V Hugh M. Smith: Cruise 20, 19°09'N, 158°22'W, April 2, 1953. Messenger time: 0307 GCT. Weather: 18, cloud coverage 9. Wind: 120°, 9 kt. Sea: 1-3 ft. Wire angle: 05°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.50	34.78	23.33		
10	24.47	34.79	23.36		
25	24.36	34.86	23.45		
55	24.38	34.97	23.53		
109	23.28	35.31	24.11		
213	18.42	34.96	25.15		
317	11.40	34.26	26.14		
425	08.08	34.23	26.68		
529	06.21	34.27	26.97		
633	05.67	34.36	27.12		
839	04.71	34.48	27.32		
1048	03.98	34.52	27.43		
1252	03.46	34.52	27.48		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.54	34.78	23.33	0.000	1.827
10	24.47	34.79	23.36	0.045	1.782
20	24.39	34.84	23.42	0.090	1.737
30	24.37	34.88	23.46	0.135	1.692
50	24.37	34.95	23.51	0.224	1.603
75	24.10	35.14	23.73	0.331	1.496
100	23.50	35.30	24.03	0.433	1.394
150	21.52	35.23	24.54	0.617	1.210
200	19.20	35.04	25.01	0.779	1.048
250	15.65	34.66	25.58	0.916	0.911
300	12.40	34.33	26.01	1.031	0.796
400	08.70	34.23	26.58	1.211	0.616
500	06.62	34.25	26.90	1.350	0.477
600	05.82	34.33	27.06	1.465	0.362
700	05.38	34.41	27.18	1.568	0.259
800	04.90	34.46	27.28	1.661	0.166
1000	04.15	34.52	27.41	1.827	0.000

STATION 61

M/V Hugh M. Smith: Cruise 20, 18°42'N, 157°53'W, April 2, 1953. Messenger time: 0920 GCT. Weather: 02, cloud coverage 7. Wind: 120°, 14 kt. Sea: 3-5 ft. Wire angle: 18°. Depth of water: 1800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.10	34.83	23.49		
10	24.13	34.83	23.50		
25	24.15	34.83	23.49		
53	23.94	34.95	23.64		
103	23.74	35.07	23.79		
200	18.94	34.97	25.03		
299	11.01	34.21	26.18		
403	09.14	34.38	26.63		
503	07.58	34.33	26.83		
604	06.62	34.36	26.99		
805	05.16	34.44	27.23		
1007	04.26	34.50	27.38		
1201	03.65	34.53	27.47		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.14	34.83	23.49	0.000	1.874
10	24.13	34.83	23.49	0.044	1.830
20	24.14	34.83	23.49	0.088	1.786
30	24.15	34.84	23.49	0.132	1.742
50	23.98	34.94	23.62	0.219	1.655
75	23.85	35.02	23.72	0.326	1.548
100	23.79	35.07	23.77	0.431	1.443
150	22.70	35.16	24.16	0.630	1.244
200	18.96	34.97	25.02	0.801	1.073
250	15.80	34.64	25.53	0.940	0.934
300	11.00	34.21	26.18	1.051	0.823
400	09.21	34.38	26.61	1.222	0.652
500	07.62	34.33	26.82	1.363	0.511
600	06.69	34.35	26.97	1.488	0.386
700	05.90	34.40	27.11	1.599	0.275
800	05.20	34.44	27.22	1.699	0.175
1000	04.30	34.50	27.37	1.874	0.000

STATION 62

M/V Hugh M. Smith: Cruise 20, 18°18'N, 157°25'W, April 2, 1953. Messenger time: 1539 GCT. Weather: 01, cloud coverage 9. Wind: 080°, 23 kt. Sea: 5-8 ft. Wire angle: 30°. Depth of water: 900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.60	34.52	23.42		
09	23.60	34.49	23.39		
22	23.60	34.52	23.42		
48	23.60	34.49	23.39		
94	22.55	34.97	24.06		
183	18.00	34.80	25.14		
269	11.30	34.19	26.11		
363	09.14	34.38	26.63		
453	07.90	34.39	26.83		
546	07.29	34.51 1/	27.01		
736	05.98	34.57 1/	27.24		
932	04.83	34.40 1/	27.24		
1127	04.18	34.52	27.41		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	23.58	34.52	23.42	0.000	1.799
10	23.60	34.49	23.39	0.045	1.754
20	23.60	34.52	23.41	0.090	1.709
30	23.60	34.52	23.41	0.135	1.664
50	23.60	34.49	23.39	0.225	1.574
75	23.53	34.81	23.65	0.335	1.464
100	22.44	34.97	24.09	0.436	1.363
150	19.35	34.89	24.86	0.612	1.187
200	17.38	34.74	25.24	0.760	1.039
250	12.58	34.25	25.91	0.884	0.915
300	10.44	34.26	26.31	0.983	0.816
400	08.59	34.38	26.71	1.142	0.657
500	07.59	34.38	26.87	1.274	0.525
600	06.93	34.38	26.96	1.398	0.401
700	06.24	34.41	27.08	1.513	0.286
800	05.56	34.46	27.20	1.617	0.182
1000	04.58	34.51	27.36	1.799	0.000

1/ Salinities doubtful, not used for interpolated tabulations.

STATION 63

M/V Hugh M. Smith: Cruise 20, 17°44'N, 156°50'W, April 3, 1953. Messenger time: 0027 GCT. Weather: 18, cloud coverage 7. Wind: 090°, 15 kt. Sea: 5-8 ft. Wire angle: 25°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.80	34.47	23.33		
09	23.78	34.46	23.32		
23	23.75	34.45	23.32		
50	23.70	34.44	23.33		
100	23.33	35.14	23.96		
192	19.40	35.05	24.97		
287	11.05	34.19	26.16		
385	08.92	34.35	26.64		
480	07.92	34.42	26.85		
576	06.64	34.42	27.03		
767	05.45	34.51	27.26		
961	04.54	34.51	27.36		
1150	03.92	34.52	27.43		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	23.78	34.47	23.32	0.000	1.825
10	23.78	34.46	23.31	0.046	1.779
20	23.77	34.45	23.31	0.091	1.734
30	23.74	34.45	23.32	0.137	1.688
50	23.70	34.44	23.32	0.229	1.596
75	23.70	34.82	23.61	0.340	1.485
100	23.35	35.14	23.95	0.444	1.381
150	21.40	35.13	24.50	0.631	1.194
200	19.00	35.02	25.05	0.793	1.032
250	15.50	34.62	25.58	0.930	0.895
300	10.66	34.20	26.23	1.038	0.787
400	08.78	34.36	26.67	1.204	0.621
500	07.64	34.42	26.89	1.339	0.486
600	06.44	34.43	27.06	1.456	0.369
700	05.83	34.48	27.18	1.560	0.265
800	05.28	34.51	27.27	1.654	0.171
1000	04.40	34.51	27.37	1.825	0.000

STATION 64

M/V Hugh M. Smith: Cruise 20, 17°19'N, 156°19'W, April 3, 1953. Messenger time: 0733 GCT. Weather: 00, cloud coverage 0. Wind: 090°, 18 kt. Sea: 3-5 ft. Wire angle: 26°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	23.50	34.61	23.50		
09	23.53	34.62	23.52		
22	23.55	34.60	23.49		
49	23.55	34.62	23.51		
97	23.55	35.02	23.81		
188	19.73	35.10	24.93		
277	12.12	34.26	26.01		
370	09.07	34.39	26.65		
460	08.05	34.48	26.88		
552	07.04	34.43	26.99		
737	05.62	34.46	27.19		
930	04.74	34.51	27.34		
1122	04.16	34.57	27.45		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	23.54	34.61	23.50	0.000	1.817
10	23.53	34.62	23.51	0.044	1.773
20	23.54	34.60	23.49	0.088	1.729
30	23.55	34.60	23.49	0.132	1.685
50	23.55	34.62	23.50	0.220	1.597
75	23.55	34.80	23.64	0.329	1.488
100	23.54	35.03	23.82	0.434	1.383
150	20.98	35.13	24.61	0.622	1.195
200	19.22	35.07	25.03	0.782	1.035
250	15.75	34.64	25.54	0.920	0.897
300	11.07	34.24	26.19	1.030	0.787
400	08.64	34.44	26.75	1.194	0.623
500	07.64	34.46	26.92	1.324	0.493
600	06.59	34.43	27.04	1.440	0.377
700	05.84	34.45	27.15	1.546	0.271
800	05.30	34.47	27.24	1.643	0.174
1000	04.53	34.54	27.38	1.817	0.000

STATION 1

M/V Hugh M. Smith: Cruise 21, 20°33'N, 157°30'W, August 5, 1953. Messenger time: 0811 GCT. Weather: 02, cloud coverage not recorded. Wind: 080°, 13 kt. Sea: 1-3 ft. Wire angle: 00°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.37	34.88	23.16		0.21
43	25.10	34.90	23.26		0.18
96	25.00	34.91	23.29		0.14
117	23.64	35.01	23.77		0.25
148	21.78	35.14	24.40		0.16
180	20.34	35.09	24.76		0.20
212	18.66	34.94	25.08		0.32
244	18.10	34.83	25.14		0.40
276	15.83	34.49	25.41		0.58
318	13.36	34.21	25.73		0.81
370	10.12	34.10	26.25		1.20
422	08.77	34.12	26.49		1.58
524	06.89	34.13	26.77		2.21

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.37	34.88	23.16	0.000	1.481
10	25.30	34.89	23.19	0.047	1.434
20	25.17	34.89	23.23	0.094	1.387
30	25.11	34.90	23.25	0.140	1.341
50	25.09	34.90	23.26	0.233	1.248
75	25.05	34.91	23.28	0.349	1.132
100	24.98	34.91	23.30	0.465	1.016
150	21.60	35.14	24.46	0.669	0.812
200	19.22	35.01	24.99	0.834	0.647
250	17.34	34.71	25.23	0.981	0.500
300	14.49	34.33	25.59	1.114	0.367
400	09.31	34.11	26.39	1.325	0.156
500	07.20	34.13	26.73	1.481	0.000

STATION 2

M/V Hugh M. Smith: Cruise 21, 21°10'N, 157°30'W, August 5, 1953. Messenger time: 1357 GCT. Weather: 00, cloud coverage not recorded. Wind: 060°, 22 kt. Sea: 3-5 ft. Wire angle: 10°. Depth of water: 300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.19	34.94	23.26		0.22
19	25.18	34.88	23.22		0.18
40	25.18	34.96	23.28		0.17
60	25.08	35.01	23.34		0.18
80	24.70	35.06	23.50		0.19
110	23.44	35.12	23.92		0.23
140	22.30	35.22	24.32		0.23
181	20.41	35.16	24.79		0.22

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.19	34.94			
10	25.19	34.91			
20	25.18	34.88			
30	25.18	34.92			
50	25.16	34.98			
75	24.73	35.06			
100	23.72	35.10			
150	22.02	35.22			

STATION 3

M/V Hugh M. Smith: Cruise 21, 21°25'N, 157°32'W, August 5, 1953. Messenger time: 1732 GCT. Weather: 02, cloud coverage 2. Wind: 070°, 13 kt. Sea: 3-5 ft. Wire angle: 20°. Depth of water: 400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.77	34.98	23.42		0.27
33	24.74	35.05	23.48		0.26
58	24.76	35.00	23.43		0.27
90	24.34	35.18	23.70		0.23
118	23.10	35.26	24.12		0.23
167	21.52	35.38	24.66		0.25
190	20.16	35.23	24.91		0.26
223	18.12	35.00	25.26		0.40
223	18.18	35.00	25.25		-
271	15.50	34.63	25.60		0.57
304	13.36	34.36	25.84		0.96
352	10.88	34.23	26.22		1.33
402	09.08	34.20	26.50		1.64
510	07.06	34.16	26.77		2.18

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.77	34.98	23.42	0.000	1.401
10	24.76	35.00	23.44	0.045	1.356
20	24.75	35.02	23.45	0.089	1.312
30	24.74	35.05	23.48	0.134	1.267
50	24.75	35.01	23.45	0.223	1.178
75	24.73	35.05	23.48	0.334	1.067
100	24.05	35.21	23.81	0.441	0.960
150	21.94	35.37	24.54	0.632	0.769
200	19.66	35.19	25.01	0.794	0.607
250	16.31	34.77	25.52	0.933	0.468
300	13.65	34.38	25.80	1.054	0.347
400	09.20	34.20	26.48	1.250	0.151
500	07.20	34.16	26.75	1.401	0.000

STATION 4

M/V Hugh M. Smith: Cruise 21, 21°52'N, 157°33'W, August 5, 1953. Messenger time: 2157 GCT. Weather: 02, cloud coverage 3. Wind: 090°, 16 kt. Sea: 1-3 ft. Wire angle: 14°. Depth of water: 1700 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.12	35.11	23.41		0.20
31	25.01	35.14	23.46		0.18
62	25.00	35.09	23.43		0.19
84	23.99	35.14	23.77		0.12
104	23.30	35.26	24.06		0.14
122	22.44	35.42	24.43		0.20
165	21.46	35.46	24.73		0.16
206	20.11	35.31	24.99		0.21
257	18.24	35.06	25.27		0.30
308	13.91	34.50	25.84		0.72
359	11.94	34.37	26.13		0.93
410	09.50	34.28	26.49		1.37
512	07.42	34.33	26.85		1.94

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.12	35.11	23.41	0.000	1.407
10	25.05	35.12	23.44	0.045	1.362
20	25.02	35.13	23.45	0.089	1.318
30	25.01	35.14	23.46	0.134	1.273
50	25.00	35.11	23.45	0.223	1.184
75	24.60	35.11	23.57	0.333	1.074
100	23.42	35.23	24.01	0.437	0.970
150	21.81	35.47	24.65	0.620	0.787
200	20.28	35.35	24.97	0.780	0.627
250	18.59	35.12	25.24	0.928	0.479
300	14.38	34.55	25.78	1.056	0.351
400	10.00	34.30	26.43	1.256	0.151
500	07.55	34.33	26.83	1.407	0.000

STATION 5

M/V Hugh M. Smith: Cruise 21, 23°36'N, 157°31'W, August 6, 1953. Messenger time: 1132 GCT. Weather: 80, cloud coverage 4. Wind: 100°, 19 kt. Sea: 3-5 ft. Wire angle: 15°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.95	34.78	23.21		0.25
31	24.96	34.85	23.26		0.23
62	24.92	34.88	23.30		0.23
83	23.66	35.00	23.76		0.23
103	22.88	35.10	24.07		0.23
134	22.05	35.25	24.41		0.21
175	20.66	35.26	24.80		0.26
206	19.55	35.12	24.99		0.31
256	17.42	34.89	25.35		0.38
309	13.26	34.38	25.88		0.75
360	11.36	34.33	26.21		0.96
412	10.02	34.28	26.41		1.17
516	07.61	34.18	26.71		1.62

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.95	34.78	23.21	0.000	1.429
10	24.95	34.80	23.23	0.047	1.382
20	24.96	34.83	23.25	0.093	1.336
30	24.96	34.85	23.26	0.140	1.289
50	24.94	34.87	23.28	0.232	1.197
75	23.98	34.97	23.65	0.344	1.085
100	23.00	35.09	24.02	0.446	0.983
150	21.61	35.31	24.58	0.630	0.799
200	19.74	35.15	24.96	0.793	0.636
250	17.73	34.92	25.30	0.939	0.490
300	13.70	34.41	25.81	1.065	0.364
400	10.39	34.28	26.34	1.267	0.162
500	07.85	34.18	26.67	1.429	0.000

STATION 6

M/V Hugh M. Smith: Cruise 21, 23°13'N, 156°60'W, August 6, 1953. Messenger time: 1807 GCT. Weather: 15, cloud coverage 2. Wind: 100, 21 kt. Sea: 5-8 ft. Wire angle: 05°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.06	35.07	23.40		0.13
26	25.20	35.39	23.59		0.07
63	24.80	35.50	23.80		0.04
88	23.16	35.39	24.20		0.02
115	22.38	35.41	24.44		0.08
150	21.11	35.39	24.78		0.12
187	19.71	35.25	25.05		0.19
228	18.38	35.00	25.20		0.24
284	14.80	34.51	25.66		0.47
340	12.46	34.32	25.99		0.71
397	10.20	34.20	26.31		1.02
452	08.68	34.17	26.54		1.31
557	06.92	34.16	26.79		1.75

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.06	35.07	23.40	0.000	1.377
10	25.07	35.10	23.42	0.045	1.332
20	25.09	35.15	23.45	0.090	1.287
30	25.20	35.40	23.60	0.133	1.244
50	25.12	35.47	23.68	0.219	1.158
75	23.45	35.39	24.12	0.320	1.057
100	22.78	35.40	24.32	0.414	0.963
150	21.11	35.39	24.78	0.586	0.791
200	19.35	35.18	25.09	0.740	0.637
250	17.08	34.79	25.35	0.882	0.495
300	14.15	34.45	25.75	1.008	0.369
400	10.11	34.19	26.32	1.215	0.162
500	07.70	34.16	26.68	1.377	0.000

STATION 7

M/V Hugh M. Smith: Cruise 21, 22°43'N, 156°24'W, August 7, 1953. Messenger time: 0050 GCT. Weather: 25, cloud coverage 7. Wind: 100°, 21 kt. Sea: 3-5 ft. Wire angle: 15°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.23	35.11	23.37		0.18
28	25.12	35.12	23.41		0.16
53	25.10	35.10	23.41		0.17
75	23.84	35.24	23.89		0.17
96	22.98	35.33	24.21		0.10
127	21.74	35.35	24.57		0.13
158	21.00	35.30	24.74		0.12
212	19.16	35.10	25.08		0.16
265	16.60	34.73	25.42		0.35
318	13.28	34.35	25.85		0.59
372	10.76	34.15	26.18		1.00
426	09.38	34.11	26.38		1.30
531	07.34	34.07	26.66		1.79

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.23	35.11	23.38	0.000	1.413
10	25.18	35.11	23.39	0.045	1.368
20	25.13	35.12	23.41	0.090	1.323
30	25.11	35.12	23.42	0.135	1.278
50	25.10	35.10	23.41	0.225	1.188
75	23.84	35.24	23.89	0.332	1.081
100	22.80	35.35	24.28	0.429	0.984
150	21.17	35.32	24.71	0.603	0.810
200	19.59	35.15	25.00	0.762	0.651
250	17.38	34.84	25.32	0.906	0.507
300	14.49	34.47	25.69	1.035	0.378
400	10.00	34.12	26.29	1.245	0.168
500	07.84	34.08	26.60	1.413	0.000

STATION 8

M/V Hugh M. Smith: Cruise 21, 22°17'N, 155°52'W, August 7, 1953. Messenger time: 0737 GCT. Weather: 25, cloud coverage not recorded. Wind: 100°, 29 kt. Sea: 5-8 ft. Wire angle: 20°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.18	35.27	23.51		0.09
32	25.09	35.33	23.58		0.08
62	23.93	35.32	23.93		0.05
79	23.23	35.33	24.14		0.05
102	22.32	35.40	24.45		0.05
127	21.42	35.36	24.67		0.07
150	20.55	35.26	24.83		0.14
201	19.20	35.11	25.07		0.25
251	16.57	34.76	25.45		0.35
301	13.66	34.39	25.80		0.58
351	11.01	34.17	26.15		0.97
402	09.69	34.12	26.34		1.21
502	07.29	34.08	26.67		1.76

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.18	35.27	23.51	0.000	1.365
10	25.17	35.28	23.52	0.044	1.321
20	25.12	35.30	23.55	0.088	1.277
30	25.10	35.33	23.58	0.131	1.234
50	25.09	35.33	23.58	0.218	1.147
75	23.31	35.34	24.12	0.320	1.045
100	22.60	35.39	24.36	0.413	0.952
150	20.55	35.26	24.83	0.583	0.782
200	19.23	35.11	25.07	0.736	0.629
250	16.65	34.77	25.44	0.876	0.489
300	13.73	34.39	25.79	0.999	0.366
400	09.78	34.13	26.33	1.203	0.162
500	07.32	34.08	26.67	1.365	0.000

STATION 9

M/V Hugh M. Smith: Cruise 21, 21°52'N, 155°23'W, August 7, 1953. Messenger time: 1437 GCT. Weather: 25, cloud coverage 3. Wind: 110°, 27 kt. Sea: 5-12 ft. Wire angle: 12°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.91	35.07	23.44		0.24
37	24.92	35.08	23.45		0.24
65	24.48	35.41	23.83		0.18
92	23.47	35.36	24.09		0.16
117	22.23	35.34	24.43		0.21
144	21.54	35.34	24.62		0.22
168	20.69	35.29	24.82		0.24
224	18.50	34.99	25.16		0.36
276	15.22	34.52	25.57		0.61
330	11.56	34.13	26.01		1.10
385	09.83	34.14	26.33		1.47
437	07.99	34.06	26.56		1.60
543	06.24	34.11	26.84		2.10

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D 1000 - \Delta D$ (dyn. m)
00	24.91	35.07	23.44	0.000	1.382
10	24.91	35.07	23.44	0.045	1.337
20	24.91	35.07	23.44	0.089	1.293
30	24.92	35.08	23.45	0.134	1.248
50	24.92	35.08	23.45	0.223	1.159
75	24.18	35.40	23.91	0.329	1.053
100	23.00	35.34	24.21	0.427	0.955
150	21.32	35.34	24.68	0.604	0.778
200	19.47	35.13	25.02	0.762	0.620
250	17.08	34.78	25.35	0.906	0.476
300	13.13	34.24	25.80	1.031	0.351
400	09.26	34.14	26.42	1.229	0.153
500	06.71	34.10	26.77	1.382	0.000

STATION 10

M/V Hugh M. Smith: Cruise 21, 21°25'N, 154°43'W, August 7, 1953. Messenger time: 2137 GCT. Weather: 02, cloud coverage 3. Wind: 090°, 18 kt. Sea: 5-8 ft. Wire angle: 20°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.89	35.26	23.59		0.23
21	24.80	35.26	23.62		0.19
44	24.53	35.36	23.77		0.17
60	23.42	35.37	24.11		0.13
81	22.38	35.71	24.67		0.11
100	21.62	35.37	24.62		0.17
150	20.24	35.29	24.94		0.15
200	18.68	35.06	25.16		0.26
251	15.02	34.51	25.61		0.58
300	12.39	34.27	25.97		0.80
352	09.92	34.14	26.31		1.19
404	08.66	34.10	26.49		1.51
509	06.77	34.12	26.78		2.05

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.89	35.26	23.59	0.000	1.293
10	24.87	35.26	23.60	0.043	1.250
20	24.81	35.26	23.62	0.086	1.207
30	24.69	35.35	23.72	0.129	1.164
50	24.46	35.36	23.80	0.212	1.081
75	22.55	35.37	24.36	0.309	0.984
100	21.62	35.37	24.62	0.396	0.897
150	20.24	35.29	24.94	0.557	0.736
200	18.68	35.06	25.17	0.705	0.588
250	15.08	34.51	25.60	0.839	0.454
300	12.39	34.27	25.97	0.954	0.339
400	08.78	34.10	26.47	1.142	0.151
500	06.85	34.12	26.77	1.293	0.000

STATION 11

M/V Hugh M. Smith: Cruise 21, 21°00'N, 154°18'W, August 8, 1953. Messenger time: 0326 GCT. Weather: 16, cloud coverage 9. Wind: 080°, 18 kt. Sea: 5-8 ft. Wire angle: 23°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.87	34.90	23.33		0.29
25	24.85	34.91	23.34		0.29
44	24.80	34.96	23.39		0.29
65	24.36	35.32	23.79		0.24
84	23.25	35.33	24.13		0.24
103	22.39	35.34	24.39		0.21
149	20.28	35.21	24.86		0.32
198	17.84	34.88	25.24		0.43
248	14.54	34.45	25.67		0.70
296	12.44	34.42	26.07		0.81
346	10.22	34.14	26.26		1.24
398	08.72	34.10	26.48		1.59
497	06.91	34.18	26.81		2.29

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.87	34.90	23.33	0.000	1.309
10	24.86	34.90	23.33	0.046	1.263
20	24.86	34.91	23.34	0.091	1.218
30	24.84	34.91	23.34	0.137	1.172
50	24.78	35.02	23.44	0.227	1.082
75	23.78	35.35	23.99	0.332	0.977
100	22.45	35.34	24.37	0.427	0.882
150	20.27	35.21	24.87	0.596	0.713
200	17.74	34.87	25.26	0.744	0.565
250	14.41	34.45	25.69	0.873	0.436
300	12.25	34.42	26.11	0.982	0.327
400	08.62	34.10	26.49	1.162	0.147
500	06.88	34.18	26.81	1.309	0.000

STATION 12

M/V Hugh M. Smith: Cruise 21, 20°34'N, 153°46'W, August 8, 1953. Messenger time: 0939 GCT. Weather: 02, cloud coverage 3. Wind: 090°, 21 kt. Sea: 5-8 ft. Wire angle: 18°. Depth of water: 2800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.79	34.85	23.31		0.25
35	24.80	34.86	23.32		0.22
65	24.41	34.85	23.43		0.21
79	23.32	35.00	23.86		0.28
99	21.72	34.90	24.24		0.30
119	19.66	34.86	24.76		0.46
163	18.08	34.82	25.13		0.54
218	15.32	34.51	25.54		0.66
271	11.91	34.19	26.00		1.39
322	09.95	34.12	26.29		1.21
377	08.26	34.08	26.53		1.72
431	07.18	34.06	26.68		2.06
538	06.04	34.22	26.95		2.37

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.79	34.85	23.31	0.000	1.284
10	24.80	34.85	23.31	0.046	1.238
20	24.80	34.86	23.32	0.092	1.192
30	24.80	34.86	23.32	0.137	1.147
50	24.71	34.86	23.34	0.229	1.055
75	23.38	35.00	23.84	0.337	0.947
100	21.58	34.89	24.27	0.435	0.849
150	18.63	34.85	25.02	0.602	0.682
200	16.76	34.68	25.34	0.745	0.539
250	12.99	34.26	25.84	0.868	0.416
300	10.85	34.14	26.15	0.972	0.312
400	07.71	34.07	26.61	1.144	0.140
500	06.29	34.11	26.83	1.284	0.000

STATION 13

M/V Hugh M. Smith: Cruise 21, 19°35'N, 154°11'W, August 8, 1953. Messenger time: 1831 GCT. Weather: 02, cloud coverage 8. Wind: 080°, 18 kt. Sea: 5-8 ft. Wire angle: > 05°. Depth of water: 3000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
04	24.64	34.80	23.32		0.34
36	24.62	34.79	23.32		0.30
58	24.42	34.88	23.44		0.32
79	23.50	34.97	23.79		0.26
102	22.70	35.15	24.15		0.21
122	21.86	35.15	24.39		0.24
166	19.93	35.07	24.85		0.39
218	18.15	34.87	25.15		0.50
273	13.84	34.33	25.72		1.04
327	10.86	34.11	26.13		1.12
382	09.26	34.14	26.42		1.67
436	07.98	34.14	26.62		2.11
542	06.51	34.21	26.88		2.35

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	24.64	34.80	23.32	0.000	1.368
10	24.63	34.80	23.32	0.046	1.322
20	24.63	34.80	23.32	0.091	1.277
30	24.62	34.79	23.32	0.137	1.231
50	24.60	34.84	23.36	0.228	1.140
75	23.80	34.95	23.68	0.338	1.030
100	22.82	35.14	24.11	0.440	0.928
150	20.60	35.11	24.71	0.619	0.749
200	18.82	34.95	25.05	0.776	0.592
250	15.70	34.55	25.49	0.915	0.453
300	12.06	34.17	25.95	1.033	0.335
400	08.80	34.14	26.50	1.220	0.148
500	06.94	34.18	26.80	1.368	0.000

STATION 14

M/V Hugh M. Smith: Cruise 21, 20°06'N, 154°39'W, August 9, 1953. Messenger time: 0102 GCT. Weather: 02, cloud coverage 8. Wind: 090°, 15 kt. Sea: 3-5 ft. Wire angle: 10°. Depth of water: 3000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.24	35.16	23.40		0.20
26	25.08	35.15	23.45		0.20
51	24.78	35.30	23.65		0.16
68	23.54	35.36	24.07		0.18
84	22.72	35.34	24.29		0.15
104	22.01	35.37	24.51		0.20
156	20.10	35.23	24.93		0.28
208	17.56	34.88	25.31		0.45
259	14.22	34.37	25.67		0.80
311	11.14	34.17	26.12		1.04
365	09.36	34.19	26.44		1.56
415	08.25	34.14	26.58		1.96
517	06.60	34.22	26.88		2.34

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.24	35.16	23.41	0.000	1.295
10	25.21	35.16	23.42	0.045	1.250
20	25.15	35.15	23.43	0.090	1.205
30	25.05	35.18	23.48	0.134	1.161
50	24.79	35.30	23.65	0.221	1.074
75	23.08	35.35	24.20	0.321	0.974
100	22.15	35.36	24.47	0.412	0.883
150	20.30	35.26	24.90	0.578	0.717
200	18.05	34.96	25.25	0.726	0.569
250	15.00	34.49	25.60	0.857	0.438
300	11.65	34.18	26.04	0.970	0.325
400	08.62	34.15	26.53	1.152	0.143
500	06.75	34.22	26.86	1.295	0.000

STATION 15

M/V Hugh M. Smith: Cruise 21, 20°29'N, 155°13'W, August 9, 1953. Messenger time: 0750 GCT. Weather: 02, cloud coverage 5. Wind: 110°, 22 kt. Sea: 5-8 ft. Wire angle: 12°. Depth of water: 1400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.94	35.26	23.57		0.19
25	24.94	35.25	23.57		0.17
56	24.78	35.35	23.69		0.11
81	24.50	35.42	23.83		0.15
102	22.60	35.35	24.33		0.12
122	21.45	35.41	24.70		0.13
162	20.00	35.24	24.96		0.26
217	17.36	34.82	25.31		0.43
273	13.86	34.38	25.75		0.67
324	11.41	34.21	26.10		0.98
379	09.32	34.12	26.40		1.42
431	08.07	34.14	26.61		1.93
540	06.26	34.18	26.89		2.48

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.94	35.26	23.58	0.000	1.322
10	24.94	35.26	23.58	0.043	1.279
20	24.94	35.25	23.57	0.087	1.235
30	24.94	35.25	23.57	0.130	1.192
50	24.93	35.28	23.59	0.217	1.105
75	24.57	35.42	23.81	0.322	1.000
100	22.70	35.35	24.31	0.420	0.902
150	20.53	35.33	24.89	0.590	0.732
200	17.90	34.90	25.24	0.738	0.584
250	15.22	34.54	25.59	0.870	0.452
300	12.61	34.28	25.93	0.896	0.336
400	08.78	34.12	26.48	1.175	0.147
500	06.79	34.17	26.82	1.322	0.000

STATION 16

M/V Hugh M. Smith: Cruise 21, 21°00'N, 155°55'W, August 9, 1953. Messenger time: 1457 GCT. Weather: 02, cloud coverage 9. Wind: 080°, 18 kt. Sea: 3-8 ft. Wire angle: 15°. Depth of water: 1800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.89	35.06	23.44		0.24
30	24.91	35.04	23.42		0.20
60	24.91	35.06	23.43		0.20
81	24.02	35.25	23.84		0.17
90	23.26	35.21	24.04		0.14
100	22.63	35.17	24.19		0.21
149	21.16	35.20	24.62		0.23
200	19.60	35.10	24.96		0.28
251	16.24	34.65	25.44		0.63
302	12.35	34.23	25.94		1.09
352	09.84	34.14	26.33		1.62
402	08.24	34.14	26.58		1.98
503	06.65	34.16	26.83		2.41

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.89	35.06	23.44	0.000	1.361
10	24.90	35.05	23.43	0.045	1.316
20	24.90	35.05	23.43	0.089	1.272
30	24.91	35.04	23.42	0.134	1.227
50	24.91	35.05	23.43	0.224	1.137
75	24.30	35.26	23.77	0.332	1.029
100	22.63	35.17	24.19	0.431	0.930
150	21.13	35.20	24.63	0.610	0.751
200	19.60	35.10	24.96	0.771	0.590
250	16.32	34.65	25.42	0.914	0.447
300	12.43	34.23	25.93	1.034	0.327
400	08.30	34.14	26.57	1.219	0.142
500	06.67	34.16	26.82	1.361	0.000

STATION 17

M/V Hugh M. Smith: Cruise 21, 21°20'N, 156°23'W, August 9, 1953. Messenger time: 2035 GCT. Weather: 02, cloud coverage 6. Wind: 070°, 22 kt. Sea: 5-8 ft. Wire angle: 25°. Depth of water: 300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.88	35.01	23.41		0.26
29	24.88	34.96	23.37		0.27
65	24.87	35.08	23.46		0.26
75	23.88	35.08	23.76		0.24
89	23.22	35.22	24.06		0.22
99	22.89	35.31	24.22		0.18
114	22.34	35.34	24.40		0.18
143	21.56	35.35	24.62		0.22
190	20.11	35.27	24.96		0.30
237	18.34	34.94	25.16		0.38
285	14.94	34.47	25.60		0.80
381	10.07	34.14	26.29		1.74
480	07.32	34.13	26.71		2.38

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.88	35.01	23.41	0.000	1.400
10	24.88	35.00	23.40	0.045	1.355
20	24.88	34.98	23.38	0.090	1.310
30	24.88	34.96	23.37	0.135	1.265
50	24.88	35.05	23.44	0.225	1.175
75	23.88	35.08	23.76	0.334	1.066
100	22.81	35.31	24.24	0.432	0.968
150	21.31	35.35	24.69	0.608	0.792
200	19.70	35.22	25.03	0.766	0.634
250	17.63	34.82	25.24	0.912	0.488
300	14.07	34.40	25.73	1.041	0.359
400	09.40	34.14	26.40	1.245	0.155
500	07.05	34.13	26.75	1.400	0.000

STATION 18

M/V Hugh M. Smith: Cruise 21, 21°48'N, 156°53'W, August 10, 1953. Messenger time: 0257 GCT. Weather: 02, cloud coverage 6. Wind: 080°, 25 kt. Sea: 5-8 ft. Wire angle: 18°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.00	35.01	23.37		0.27
28	25.01	35.04	23.39		0.27
63	25.00	35.01	23.37		0.23
81	24.25	35.18	23.72		0.21
97	23.70	35.19	23.89		0.19
112	22.80	35.20	24.16		0.23
126	22.31	35.22	24.32		0.22
156	21.64	35.34	24.59		0.22
207	20.26	35.30	24.94		0.23
259	17.64	34.87	25.28		0.40
309	14.46	34.43	25.67		0.73
414	09.48	34.09	26.35		1.65
517	07.22	34.14	26.73		2.30

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.00	35.01	23.37	0.000	1.457
10	25.00	35.02	23.38	0.045	1.412
20	25.01	35.03	23.38	0.090	1.367
30	25.01	35.04	23.39	0.136	1.321
50	25.00	35.03	23.38	0.226	1.231
75	24.80	35.12	23.51	0.338	1.119
100	23.56	35.18	23.93	0.443	1.014
150	21.76	35.33	24.56	0.630	0.827
200	20.55	35.33	24.89	0.795	0.662
250	18.12	34.95	25.22	0.944	0.513
300	15.01	34.51	25.61	1.077	0.380
400	10.08	34.10	26.26	1.294	0.163
500	07.37	34.15	26.72	1.457	0.000

STATION 19

M/V Hugh M. Smith: Cruise 21, 22°17'N, 157°26'W, August 10, 1953. Messenger time: 0917 GCT. Weather: 02, cloud coverage 2. Wind: 070°, 20 kt. Sea: 5-8 ft. Wire angle: 12°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.94	35.01	23.39		0.34
32	24.96	35.03	23.40		0.33
66	24.96	35.07	23.43		0.28
88	24.19	35.23	23.78		0.24
109	22.68	35.24	24.23		0.27
131	22.08	35.33	24.46		0.26
163	21.52	35.42	24.69		0.27
217	20.77	35.36	24.85		0.29
270	18.60	35.05	25.18		0.39
324	14.52	34.44	25.66		0.72
381	11.18	34.26	26.19		1.25
434	09.13	34.30	26.57		1.76
541	06.84	34.32	26.93		2.56

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.94	35.01	23.39	0.000	1.453
10	24.94	35.02	23.40	0.045	1.408
20	24.95	35.02	23.39	0.090	1.363
30	24.96	35.03	23.40	0.135	1.318
50	24.96	35.05	23.41	0.225	1.228
75	24.52	35.21	23.67	0.335	1.118
100	22.95	35.23	24.14	0.436	1.017
150	21.78	35.40	24.60	0.616	0.837
200	20.97	35.39	24.82	0.782	0.671
250	19.54	35.19	25.05	0.937	0.516
300	16.41	34.72	25.46	1.078	0.375
400	10.36	34.26	26.33	1.299	0.154
500	07.40	34.32	26.85	1.453	0.000

STATION 20

M/V Hugh M. Smith: Cruise 21, 22°40'N, 157°56'W, August 10, 1953. Messenger time: 1545 GCT. Weather: 02, cloud coverage 3. Wind: 070°, 19 kt. Sea: 5-8 ft. Wire angle: 12°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.02	35.00	23.35		0.28
26	25.03	34.99	23.34		0.25
53	25.02	34.97	23.33		0.25
73	24.86	34.99	23.40		0.29
90	24.64	35.09	23.54		0.26
107	23.69	35.08	23.81		0.29
159	21.70	35.34	24.58		0.29
212	20.16	35.25	24.93		0.37
266	17.90	34.88	25.22		0.49
319	14.28	34.34	25.64		0.94
373	11.04	34.21	26.17		1.31
428	09.72	34.12	26.33		1.78
533	07.65	34.09	26.63		2.28

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.02	35.00	23.36	0.000	1.495
10	25.02	35.00	23.36	0.045	1.450
20	25.03	34.99	23.35	0.091	1.404
30	25.03	34.98	23.34	0.136	1.359
50	25.02	34.97	23.33	0.228	1.267
75	24.85	35.02	23.42	0.341	1.154
100	24.00	35.08	23.72	0.450	1.045
150	22.01	35.31	24.47	0.644	0.851
200	20.53	35.31	24.88	0.811	0.684
250	18.59	35.00	25.14	0.963	0.532
300	15.61	34.50	25.47	1.101	0.394
400	10.37	34.17	26.26	1.324	0.171
500	08.06	34.09	26.57	1.495	0.000

STATION 21

M/V Hugh M. Smith: Cruise 21, 23°08'N, 158°27'W, August 10, 1953. Messenger time: 2202 GCT. Weather: 01, cloud coverage 2. Wind: 080°, 21 kt. Sea: 5-8 ft. Wire angle: 15°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.40	35.07	23.29		0.30
25	25.38	35.07	23.30		0.29
45	25.45	35.17	23.35		0.24
64	25.49	35.30	23.44		0.20
79	25.34	35.28	23.47		0.18
98	23.96	35.37	23.95		0.15
153	21.18	35.29	24.68		0.17
203	18.94	35.04	25.09		0.26
259	16.10	34.58	25.42		0.73
313	13.31	34.27	25.78		0.85
367	10.76	34.12	26.15		1.29
423	09.21	34.04	26.35		1.57
528	07.06	34.01	26.65		2.14

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.40	35.07	23.29	0.000	1.436
10	25.39	35.07	23.30	0.046	1.390
20	25.37	35.07	23.30	0.092	1.344
30	25.36	35.08	23.31	0.138	1.298
50	25.48	35.24	23.40	0.229	1.207
75	25.44	35.30	23.45	0.341	1.095
100	23.87	35.37	23.98	0.447	0.989
150	21.24	35.30	24.68	0.629	0.807
200	19.10	35.06	25.06	0.787	0.649
250	16.48	34.64	25.38	0.929	0.507
300	14.09	34.34	25.68	1.056	0.380
400	09.81	34.07	26.28	1.268	0.168
500	07.44	34.01	26.60	1.436	0.000

STATION 22

M/V Hugh M. Smith: Cruise 21, 23°35'N, 159°05'W, August 11, 1953. Messenger time: 0445 GCT. Weather: 02, cloud coverage 3. Wind: 070°, 18 kt. Sea: 5-8 ft. Wire angle: 12°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.47	35.22	23.38		0.21
28	25.43	35.22	23.40		0.19
51	25.41	35.20	23.39		0.20
72	23.68	35.18	23.89		0.23
82	23.33	35.21	24.02		0.21
103	22.56	35.27	24.28		0.24
124	21.78	35.30	24.53		0.28
154	20.90	35.26	24.73		0.25
206	19.36	35.12	25.04		0.27
257	16.31	34.68	25.45		0.55
309	13.50	34.36	25.81		0.81
411	10.38	34.15	26.24		1.26
513	08.04	34.05	26.54		1.91

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.47	35.22	23.38	0.000	1.418
10	25.46	35.22	23.39	0.045	1.373
20	25.45	35.22	23.39	0.090	1.328
30	25.43	35.22	23.40	0.135	1.283
50	25.41	35.20	23.39	0.226	1.192
75	23.58	35.18	23.92	0.332	1.086
100	22.68	35.25	24.24	0.429	0.989
150	21.01	35.27	24.72	0.605	0.813
200	19.59	35.15	25.00	0.763	0.655
250	16.75	34.74	25.39	0.906	0.512
300	13.88	34.40	25.77	1.030	0.388
400	10.69	34.17	26.20	1.242	0.176
500	08.22	34.06	26.52	1.418	0.000

STATION 24 [1/]

M/V Hugh M. Smith: Cruise 21, 22°40'N, 159°42'W, August 11, 1953. Messenger time: 1506 GCT. Weather: 02, cloud coverage 2. Wind: 080°, 20 kt. Sea: 5-8 ft. Wire angle: 25°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.09	34.97	23.31		0.32
29	25.11	34.94	23.28		0.30
52	25.12	34.96	23.30		0.29
72	24.86	34.92	23.34		0.32
91	24.11	35.08	23.69		0.25
114	22.92	35.20	24.13		0.25
143	21.96	35.25	24.45		0.26
189	20.83	35.28	24.77		0.28
236	19.52	35.13	25.00		0.34
286	17.06	34.70	25.29		0.58
335	13.14	34.21	25.77		1.30
382	10.96	34.13	26.13		1.58
479	08.12	34.10	26.57		1.98

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.09	34.97	23.31	0.000	1.499
10	25.10	34.96	23.30	0.046	1.453
20	25.10	34.95	23.29	0.092	1.407
30	25.11	34.94	23.28	0.138	1.361
50	25.12	34.96	23.30	0.230	1.269
75	24.80	34.93	23.37	0.345	1.154
100	23.80	35.12	23.81	0.453	1.046
150	21.75	35.26	24.50	0.644	0.855
200	20.56	35.27	24.84	0.811	0.688
250	19.05	35.05	25.07	0.966	0.533
300	15.65	34.49	25.45	1.106	0.393
400	10.20	34.12	26.25	1.330	0.169
500	07.75	34.10	26.63	1.499	0.000

1/ Station 23 was a trawl station.

STATION 25

M/V Hugh M. Smith: Cruise 21, 22°22'N, 159°13'W, August 11, 1953. Messenger time: first cast 2123 GCT, second cast 2141 GCT. Weather: 02, cloud coverage 2. Wind: 080°, 21 kt. Sea: 5-8 ft. Wire angle: first cast 18°, second cast 18°. Depth of water: 1600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.08	34.99	23.33		0.27
32	25.02	34.98	23.34		0.26
64	25.04	34.98	23.33		0.25
88	24.44	35.06	23.58		0.21
102	23.56	35.14	23.90		0.17
131	22.72	35.16	24.16		0.25
160	21.72	35.35	24.58		0.21
199	20.21	35.17	24.85		0.29
249	18.68	34.98	25.11		0.36
305	14.81	34.43	25.59		0.67
357	11.16	34.19	26.14		1.45
357	11.47	34.19	26.08		-
407	09.92	34.10	26.28		1.68
512	07.18	34.09	26.70		2.24

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.08	34.99	23.33	0.000	1.484
10	25.07	34.99	23.33	0.046	1.438
20	25.05	34.98	23.33	0.091	1.393
30	25.02	34.98	23.34	0.137	1.347
50	25.03	34.98	23.34	0.228	1.256
75	25.02	34.98	23.34	0.343	1.141
100	23.61	35.14	23.88	0.451	1.033
150	22.15	35.23	24.37	0.643	0.841
200	20.20	35.17	24.86	0.813	0.671
250	18.64	34.98	25.12	0.966	0.518
300	15.21	34.48	25.54	1.103	0.381
400	10.13	34.15	26.29	1.321	0.163
500	07.32	34.10	26.69	1.484	0.000

STATION 26

M/V Hugh M. Smith: Cruise 21, 21°58'N, 158°39'W, August 12, 1953. Messenger time: 0406 GCT. Weather: 02, cloud coverage 4. Wind: 060°, 19 kt. Sea: 3-8 ft. Wire angle: 15°. Depth of water: 900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.00	34.55	23.02		0.35
15	25.02	34.59	23.05		0.33
36	25.00	34.61	23.07		0.34
52	24.91	34.70	23.16		0.33
67	24.10	34.86	23.53		0.28
84	23.28	34.98	23.86		0.28
105	22.54	35.06	24.13		0.28
157	21.22	35.14	24.56		0.33
209	19.22	34.97	24.96		0.47
262	15.27	34.45	25.51		0.76
315	12.92	34.26	25.86		1.19
419	08.22	34.18	26.62		2.11
525	06.32	34.14	26.86		2.77

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.00	34.55	23.02	0.000	1.415
10	25.01	34.57	23.03	0.048	1.367
20	25.02	34.58	23.04	0.097	1.318
30	25.01	34.60	23.06	0.145	1.270
50	24.92	34.69	23.15	0.241	1.174
75	23.68	34.94	23.71	0.353	1.062
100	22.70	35.05	24.08	0.455	0.960
150	21.41	35.15	24.52	0.639	0.776
200	19.59	35.03	24.91	0.804	0.611
250	15.99	34.55	25.42	0.948	0.467
300	13.61	34.30	25.75	1.072	0.343
400	09.00	34.19	26.50	1.270	0.145
500	06.54	34.16	26.84	1.415	0.000

STATION 27

M/V Hugh M. Smith: Cruise 21, 21°17'N, 158°18'W, August 12, 1953. Messenger time: 1051 GCT. Weather: 02, cloud coverage 2. Wind: 090°, 13 kt. Sea: < 1 ft. Wire angle: 06°. Depth of water: 1000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.84	34.94	23.06		0.29
20	25.86	34.91	23.03		0.27
40	25.86	34.87	23.00		0.26
61	25.23	34.83	23.16		0.31
76	25.04	35.00	23.35		0.26
91	24.38	34.88	23.46		0.30
122	21.82	35.13	24.39		0.32
152	20.12	35.07	24.80		0.43
203	18.04	34.87	25.18		0.51
253	15.69	34.59	25.52		0.65
304	11.90	34.23	26.03		1.22
406	08.34	34.11	26.54		1.96
506	06.74	34.20	26.85		2.39

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.84	34.94	23.06	0.000	1.398
10	25.85	34.93	23.05	0.048	1.350
20	25.86	34.91	23.03	0.097	1.301
30	25.87	34.89	23.01	0.145	1.253
50	25.80	34.86	23.01	0.243	1.155
75	25.08	34.99	23.33	0.361	1.037
100	24.21	34.91	23.53	0.474	0.924
150	20.17	35.09	24.80	0.664	0.734
200	18.21	34.89	25.15	0.816	0.582
250	15.92	34.62	25.49	0.953	0.445
300	12.18	34.25	25.99	1.069	0.329
400	08.48	34.11	26.52	1.254	0.144
500	06.74	34.20	26.85	1.398	0.000

STATION 28

M/V Hugh M. Smith: Cruise 21, 21°51'N, 157°37'W, August 14, 1953. Messenger time: 0406 GCT. Weather: 02, cloud coverage 4. Wind: 090°, 16 kt. Sea: 1-3 ft. Wire angle: 15°. Depth of water: 1200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.13	35.09	23.39		0.22
10	25.12	35.04	23.36		0.25
25	24.96	34.96	23.34		0.23
49	24.94	34.95	23.34		0.27
69	23.82	35.06	23.76		0.20
88	22.95	35.09	24.04		0.19
116	22.34	35.15	24.26		0.26
146	21.82	35.31	24.52		0.25
195	21.08	35.32	24.73		0.23
244	19.83	35.24	25.01		0.29
293	17.26	34.73	25.26		0.48
391	10.01	34.07	26.24		1.65
490	08.02	34.12	26.60		2.08

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D 1000 - \Delta D$ (dyn. m)
00	25.13	35.09	23.39	0.000	1.481
10	25.12	35.04	23.36	0.045	1.436
20	24.99	34.98	23.35	0.091	1.390
30	24.96	34.96	23.34	0.136	1.345
50	24.94	34.95	23.34	0.227	1.254
75	23.41	35.08	23.90	0.335	1.146
100	22.61	35.10	24.14	0.433	1.048
150	21.80	35.30	24.52	0.616	0.865
200	20.94	35.32	24.77	0.784	0.697
250	19.66	35.20	25.02	0.942	0.539
300	16.80	34.67	25.33	1.086	0.395
400	09.73	34.08	26.30	1.314	0.167
500	07.95	34.12	26.61	1.481	0.000

STATION 29

M/V Hugh M. Smith: Cruise 21, 21°24'N, 157°34'W, August 14, 1953. Messenger time: 0924 GCT. Weather: 01, cloud coverage 3. Wind: 070°, 20 kt. Sea: 3-5 ft. Wire angle: 12°. Depth of water: 400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.18	35.06	23.35		0.36
25	24.84	35.08	23.47		0.27
44	24.82	34.96	23.39		0.28
70	24.18	35.09	23.67		0.24
104	22.68	35.16	24.17		0.21
126	21.97	35.25	24.43		0.28
146	21.61	35.25	24.54		0.26
179	21.11	35.19	24.63		0.24
213	19.81	35.07	24.88		0.34
262	16.80	34.71	25.36		0.55
311	13.34	34.24	25.75		0.89
413	09.32	34.05	26.34		1.91
515	06.72	34.05	26.73		-

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.18	35.06	23.35	0.000	1.443
10	25.18	35.06	23.35	0.045	1.398
20	24.85	35.08	23.47	0.090	1.353
30	24.84	35.06	23.46	0.135	1.308
50	24.82	34.95	23.38	0.225	1.218
75	23.80	35.10	23.80	0.333	1.110
100	22.80	35.14	24.12	0.433	1.010
150	21.56	35.24	24.54	0.615	0.828
200	20.39	35.12	24.77	0.783	0.660
250	17.99	34.84	25.17	0.937	0.506
300	14.01	34.33	25.69	1.069	0.374
400	09.80	34.06	26.27	1.281	0.162
500	06.86	34.06	26.72	1.443	0.000

STATION 30

M/V Hugh M. Smith: Cruise 21, 21°02'N, 157°31'W, August 14, 1953. Messenger time: 1347 GCT. Weather: 02, cloud coverage 3. Wind: 030°, 12 kt. Sea: 1-3 ft. Wire angle: 00°. Depth of water: 30 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.14	35.16	23.13		0.32
10	26.15	35.01	23.01		0.33
20	26.13	34.97	22.99		0.31
30	25.10	35.06	23.38		0.32
46	24.48	35.03	23.54		0.29

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)

STATION 31

M/V Hugh M. Smith: Cruise 21, 20°33'N, 157°30'W, August 14, 1953. Messenger time: 1910 GCT. Weather: 02, cloud coverage 9. Wind: 030°, 13 kt. Sea: 1-3 ft. Wire angle: 00°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.06	34.90	22.96		0.31
09	26.03	34.93	22.99		0.25
25	25.88	34.90	23.02		0.27
51	25.70	34.88	23.06		0.27
71	25.33	34.84	23.14		0.25
91	24.97	34.82	23.24		0.29
123	23.74	34.95	23.70		0.21
154	22.19	35.18	24.32		0.25
204	19.68	35.02	24.88		0.39
256	16.32	34.56	25.35		0.71
307	12.72	34.18	25.83		1.04
408	08.74	34.02	26.41		2.02
509	06.90	34.07	26.72		2.60

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.06	34.90	22.96	0.000	1.496
10	26.03	34.93	22.99	0.049	1.447
20	25.95	34.91	23.00	0.098	1.398
30	25.87	34.90	23.02	0.147	1.349
50	25.70	34.88	23.06	0.244	1.252
75	25.24	34.83	23.16	0.363	1.133
100	24.74	34.83	23.31	0.481	1.015
150	22.49	35.16	24.22	0.690	0.806
200	19.92	35.06	24.85	0.864	0.632
250	16.70	34.62	25.31	1.012	0.484
300	13.10	34.22	25.79	1.138	0.358
400	08.98	34.03	26.38	1.339	0.157
500	06.97	34.08	26.72	1.496	0.000

STATION 32

M/V Hugh M. Smith: Cruise 21, 20°38'N, 157°01'W, August 14, 1953. Messenger time: 2340 GCT. Weather: 02, cloud coverage 9. Wind: Calm. Sea: < 1 ft. Wire angle: 02°. Depth of water: 300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.86	34.96	23.07		0.32
15	25.18	34.97	23.29		0.35
30	25.04	34.96	23.32		0.32
49	24.86	34.97	23.38		0.31
71	23.89	35.03	23.72		0.30
85	22.82	35.15	24.12		0.38
102	22.52	35.17	24.22		0.32
156	20.57	35.12	24.72		0.47
207	18.50	34.87	25.07		0.61
265	14.67	34.41	25.61		0.96
313	11.39	34.15	26.06		1.48
413	08.90	34.12	26.46		2.12
514	06.80	-	-		2.85

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.86	34.96	23.07	0.000	1.377
10	25.32	34.97	23.24	0.047	1.330
20	25.11	34.97	23.31	0.093	1.284
30	25.04	34.96	23.32	0.139	1.238
50	24.85	34.97	23.39	0.230	1.147
75	23.78	35.04	23.76	0.339	1.038
100	22.55	35.17	24.21	0.438	0.939
150	20.80	35.13	24.67	0.616	0.761
200	18.83	34.92	25.02	0.775	0.602
250	15.68	34.52	25.47	0.915	0.462
300	11.99	34.18	25.97	1.032	0.345
400	09.27	34.12	26.41	1.223	0.154
500	06.95	34.12	26.75	1.377	0.000

STATION 34 [1/]

M/V Hugh M. Smith: Cruise 21, 20°12'N, 156°40'W, August 15, 1953. Messenger time: 0829 GCT. Weather: 02, cloud coverage 3. Wind: 060°, 19 kt. Sea: 3-5 ft. Wire angle: 18°. Depth of water: 1600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
01	26.00	34.96	23.02		0.31
15	26.00	34.95	23.01		0.31
31	25.98	34.94	23.01		0.31
45	25.27	34.98	23.27		0.31
71	24.52	35.07	23.56		0.30
100	23.20	35.15	24.01		0.33
148	20.98	35.17	24.64		0.38
199	19.06	35.07	25.08		0.51
249	16.11	34.60	25.44		0.80
298	12.54	34.23	25.91		1.25
348	10.39	34.08	26.19		1.48
397	08.94	34.11	26.45		1.81
496	06.98	34.11	26.74		2.62

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.00	34.96	23.02	0.000	1.391
10	26.00	34.95	23.02	0.049	1.342
20	26.00	34.95	23.02	0.097	1.294
30	25.99	34.94	23.01	0.146	1.245
50	25.13	35.00	23.32	0.240	1.151
75	24.49	35.07	23.57	0.352	1.039
100	23.20	35.15	24.01	0.456	0.935
150	20.60	35.16	24.74	0.637	0.754
200	19.00	35.06	25.09	0.792	0.599
250	15.94	34.59	25.46	0.931	0.460
300	12.44	34.23	25.93	1.050	0.341
400	08.84	34.11	26.47	1.240	0.151
500	06.91	34.11	26.75	1.391	0.000

1/ Station 33 was a "Q-cast".

STATION 35

M/V Hugh M. Smith: Cruise 21, 19°43'N, 156°11'W, August 15, 1953. Messenger time: 1500 GCT. Weather: 02, cloud coverage 7. Wind: Calm. Sea: < 1 ft. Wire angle: 05°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.24	34.92	22.92		0.34
15	25.92	34.92	23.02		0.33
31	25.82	34.90	23.04		0.35
63	25.43	34.87	23.13		0.35
79	25.32	34.91	23.20		0.34
95	25.10	35.05	23.37		0.30
124	23.10	35.12	24.02		0.32
157	21.14	35.21	24.63		0.34
209	17.98	34.90	25.22		0.60
262	15.18	34.51	25.57		0.87
312	12.04	34.22	26.00		1.35
416	08.65	34.13	26.51		2.20
518	07.07	34.24	26.83		2.85

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.24	34.92	22.92	0.000	1.444
10	25.97	34.92	23.00	0.049	1.395
20	25.88	34.91	23.02	0.098	1.346
30	25.86	34.90	23.02	0.146	1.298
50	25.68	34.89	23.07	0.243	1.201
75	25.35	34.89	23.17	0.363	1.081
100	25.20	35.00	23.30	0.480	0.964
150	21.95	35.17	24.38	0.686	0.758
200	18.10	34.91	25.20	0.847	0.597
250	15.53	34.55	25.53	0.982	0.462
300	12.70	34.27	25.91	1.100	0.344
400	09.12	34.12	26.43	1.293	0.151
500	07.22	34.23	26.80	1.444	0.000

STATION 36

M/V Hugh M. Smith: Cruise 21, 18°50'N, 155°59'W, August 16, 1953. Messenger time: 0010 GCT. Weather: 01, cloud coverage 5. Wind: 090°, 21 kt. Sea: 3-5 ft. Wire angle: 18°. Depth of water: 1400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.90	34.85	22.97		0.39
23	25.82	34.88	23.02		0.38
46	25.78	34.89	23.04		0.38
74	25.58	34.85	23.07		0.39
102	25.40	34.85	23.13		0.42
125	25.12	34.95	23.29		0.37
151	22.30	35.09	24.22		0.32
189	19.98	34.99	24.78		0.52
224	18.56	34.83	25.02		0.59
270	15.32	34.42	25.47		1.01
320	11.27	34.08	26.03		1.61
425	08.28	34.17	26.60		2.58
531	06.83	34.14	26.79		2.98

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.90	34.85	22.97	0.000	1.492
10	25.87	34.86	22.99	0.049	1.443
20	25.84	34.87	23.01	0.098	1.394
30	25.80	34.89	23.03	0.146	1.346
50	25.74	34.87	23.04	0.244	1.248
75	25.54	34.85	23.08	0.365	1.127
100	25.41	34.85	23.12	0.485	1.007
150	22.37	35.09	24.20	0.699	0.793
200	19.62	34.95	24.84	0.873	0.619
250	16.74	34.60	25.29	1.022	0.470
300	12.70	34.15	25.81	1.148	0.344
400	08.85	34.16	26.51	1.342	0.150
500	07.22	34.15	26.74	1.492	0.000

STATION 37

M/V Hugh M. Smith: Cruise 21, 19°20'N, 156°32'W, August 16, 1953. Messenger time: 0745 GCT. Weather: 02, cloud coverage 3. Wind: 220°, 14 kt. Sea: < 1 ft. Wire angle: 23°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.34	34.98	22.93		0.31
10	25.60	34.96	23.15		0.31
23	25.51	35.01	23.21		0.27
36	25.16	34.99	23.31		0.30
59	23.90	35.14	23.80		0.29
69	23.14	35.17	24.04		0.33
91	22.30	35.16	24.27		0.29
136	20.80	35.17	24.69		0.40
182	18.16	34.88	25.16		0.62
229	15.08	34.49	25.58		0.93
275	12.79	34.22	25.85		1.31
365	09.24	34.22	26.49		2.10
456	07.60	34.16	26.69		2.62

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.34	34.98	22.93	0.000	1.302
10	25.60	34.96	23.15	0.048	1.254
20	25.53	35.00	23.20	0.096	1.206
30	25.25	35.00	23.29	0.142	1.160
50	24.68	35.02	23.47	0.233	1.069
75	22.80	35.17	24.14	0.336	0.966
100	22.02	35.16	24.35	0.429	0.873
150	19.89	35.10	24.89	0.597	0.705
200	16.92	34.72	25.34	0.743	0.559
250	13.90	34.34	25.72	0.870	0.432
300	11.72	34.20	26.04	0.980	0.322
400	08.54	34.22	26.60	1.158	0.144
500	07.00	34.16	26.78	1.302	0.000

STATION 38

M/V Hugh M. Smith: Cruise 21, 19°38'N, 157°09'W, August 16, 1953. Messenger time: 1345 GCT. Weather: 62, cloud coverage not recorded. Wind: 170°, 19 kt. Sea: 3-5 ft. Wire angle: 24°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
02	25.81	34.89	23.03		0.33
13	25.82	34.90	23.04		0.34
13	25.82	34.72	22.90		-
28	25.80	34.89	23.03		0.37
48	25.12	34.94	23.28		0.30
75	24.37	35.02	23.57		0.28
104	22.45	35.13	24.21		0.35
157	20.56	35.17	24.76		0.32
207	18.03	34.88	25.19		0.54
259	15.44	34.54	25.54		0.68
311	11.72	34.14	25.99		1.31
365	10.16	34.14	26.27		1.65
417	08.88	34.12	26.47		1.94
522	06.60	34.16	26.83		2.65

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.81	34.89	23.03	0.000	1.392
10	25.82	34.90	23.04	0.048	1.344
20	25.81	34.89	23.03	0.097	1.295
30	25.78	34.89	23.04	0.145	1.247
50	25.03	34.95	23.32	0.240	1.152
75	24.37	35.02	23.57	0.352	1.040
100	22.80	35.12	24.10	0.455	0.937
150	20.79	35.17	24.70	0.634	0.758
200	18.08	34.89	25.19	0.788	0.604
250	16.20	34.63	25.44	0.925	0.467
300	12.22	34.16	25.91	1.045	0.347
400	09.28	34.13	26.41	1.238	0.154
500	07.07	34.15	26.76	1.392	0.000

STATION 39

M/V Hugh M. Smith: Cruise 21, 20°07'N, 157°37'W, August 16, 1953. Messenger time: 2051 GCT. Weather: 02, cloud coverage 9. Wind: 090°, 18 kt. Sea: 3-5 ft. Wire angle: 12°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.88	34.90	23.01		0.41
20	25.78	34.92	23.06		0.39
45	25.58	34.93	23.13		0.29
65	25.46	34.94	23.18		0.33
98	25.07	34.92	23.28		0.20
129	24.15	35.23	23.79		0.27
163	21.38	35.18	24.55		0.12
204	19.98	35.13	24.88		0.50
259	16.69	34.72	25.39		0.93
314	13.24	34.34	25.85		1.04
369	10.34	34.34	26.40		1.48
423	08.97	34.20	26.52		2.14
529	06.72	34.17	26.83		2.66

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D 1000 - \Delta D$ (dyn. m)
00	25.88	34.90	23.02	0.000	1.484
10	25.84	34.91	23.04	0.049	1.435
20	25.78	34.92	23.06	0.097	1.387
30	25.63	34.93	23.12	0.145	1.339
50	25.54	34.94	23.15	0.240	1.244
75	25.30	34.93	23.22	0.358	1.126
100	25.06	34.92	23.28	0.475	1.009
150	22.31	35.20	24.30	0.683	0.801
200	20.12	35.14	24.86	0.855	0.629
250	17.38	34.82	25.30	1.003	0.481
300	14.20	34.40	25.70	1.131	0.353
400	09.50	34.26	26.48	1.333	0.151
500	07.32	34.17	26.74	1.484	0.000

STATION 40

M/V Hugh M. Smith: Cruise 21, 20°35'N, 158°07'W,
August 17, 1953. Messenger time: 0545 GCT.
Weather: 02, cloud coverage 9. Wind: 020°, 13 kt.
Sea: 1-3 ft. Wire angle: 08°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.36	34.97	22.92		0.36
10	26.30	34.97	22.94		0.34
21	26.03	34.95	23.00		0.40
41	26.02	34.96	23.01		0.36
62	25.74	34.97	23.11		0.34
103	24.93	-	-		-
154	22.16	35.21	24.35		0.30
206	20.03	34.99	24.76		0.38
258	16.48	34.63	25.37		0.82
310	12.44	34.27	25.96		1.13
362	10.38	34.17	26.26		1.54
412	09.14	34.14	26.44		1.87
514	07.03	34.15	26.76		2.52

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.36	34.97	22.92	0.000	1.490
10	26.30	34.97	22.94	0.049	1.441
20	26.03	34.95	23.01	0.099	1.391
30	26.03	34.95	23.01	0.147	1.343
50	25.90	34.96	23.06	0.244	1.246
75	25.54	34.98	23.18	0.364	1.126
100	25.09	35.01	23.34	0.481	1.009
150	22.41	35.21	24.28	0.688	0.802
200	20.27	35.02	24.72	0.863	0.627
250	16.90	34.67	25.30	1.014	0.476
300	13.01	34.32	25.88	1.138	0.352
400	09.41	34.15	26.41	1.334	0.156
500	07.30	34.15	26.73	1.490	0.000

STATION 41

M/V Hugh M. Smith: Cruise 21, 21°03'N, 158°42'W, August 17, 1953. Messenger time: 1230 GCT. Weather: 02, cloud coverage not recorded. Wind: 090°, 19 kt. Sea: 3-5 ft. Wire angle: 30°. Depth of water: 2000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.42	35.05	22.96		0.34
08	26.42	35.06	22.97		0.30
17	26.32	35.04	22.99		0.27
39	25.88	35.07	23.15		0.29
53	25.36	35.04	23.28		0.26
79	23.52	35.16	23.92		0.27
106	22.12	35.19	24.35		0.25
133	21.21	35.16	24.57		0.36
176	18.76	35.15	25.21		0.56
221	16.26	34.80	25.55		0.73
266	13.38	34.31	25.80		1.19
353	10.01	34.11	26.27		1.70
442	07.84	34.10	26.61		2.20

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.42	35.05	22.96	0.000	1.339
10	26.41	35.06	22.97	0.049	1.290
20	26.05	35.07	23.09	0.098	1.241
30	25.94	35.07	23.13	0.145	1.194
50	25.52	35.04	23.23	0.240	1.099
75	23.78	35.15	23.84	0.349	0.990
100	22.40	35.19	24.27	0.447	0.892
150	20.40	35.15	24.79	0.620	0.719
200	17.40	35.00	25.44	0.766	0.573
250	14.25	34.44	25.72	0.890	0.449
300	11.90	34.18	25.99	1.001	0.338
400	08.80	34.10	26.47	1.188	0.151
500	06.85	34.12	26.77	1.339	0.000

STATION 42

M/V Hugh M. Smith: Cruise 21, 21°29'N, 159°14'W, August 17, 1953. Messenger time: 1847 GCT. Weather: 15, cloud coverage 7. Wind: 090°, 15 kt. Sea: 1-3 ft. Wire angle: 20°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.26	34.98	22.96		0.34
17	26.24	34.98	22.96		0.35
32	25.98	34.96	23.03		0.30
49	25.78	34.99	23.11		0.31
66	25.22	35.00	23.29		0.30
98	23.36	35.10	23.93		0.26
126	22.13	35.23	24.37		0.28
159	21.22	35.19	24.59		0.30
205	19.28	35.03	24.99		0.44
247	16.50	34.63	25.37		0.69
294	13.69	34.33	25.75		1.02
390	08.97	34.06	26.41		1.90
487	07.16	34.10	26.71		2.55

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.26	34.98	22.96	0.000	1.432
10	26.24	34.98	22.96	0.049	1.383
20	26.22	34.98	22.97	0.098	1.334
30	26.12	34.97	22.99	0.147	1.285
50	25.75	34.99	23.12	0.244	1.188
75	24.63	35.02	23.49	0.359	1.073
100	23.20	35.12	23.99	0.464	0.968
150	21.51	35.21	24.53	0.650	0.782
200	19.60	35.06	24.93	0.814	0.618
250	16.27	34.61	25.40	0.958	0.474
300	13.35	34.30	25.80	1.082	0.350
400	08.73	34.06	26.45	1.279	0.153
500	06.95	34.11	26.75	1.432	0.000

STATION 43

M/V Hugh M. Smith: Cruise 21, 22°19'N, 160°20'W, August 18, 1953. Messenger time: 0514 GCT. Weather: 02, cloud coverage 9. Wind: 080°, 12 kt. Sea: 1-3 ft. Wire angle: 10°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.63	34.97	23.14		0.31
16	25.44	34.97	23.20		0.25
35	25.20	34.94	23.26		0.34
61	25.15	34.93	23.26		0.39
80	24.78	34.97	23.40		0.31
101	23.36	35.09	23.92		0.22
120	22.60	35.14	24.18		0.33
151	21.80	35.26	24.49		0.29
201	20.40	35.24	24.86		0.37
251	19.24	35.10	25.05		0.35
302	16.14	34.62	25.44		0.70
403	09.78	34.10	26.31		1.70
503	07.16	34.06	26.68		2.61

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D 1000 - \Delta D$ (dyn. m)
00	25.63	34.97	23.15	0.000	1.498
10	25.51	34.97	23.18	0.047	1.451
20	25.39	34.96	23.21	0.094	1.404
30	25.26	34.95	23.25	0.141	1.357
50	25.16	34.93	23.26	0.234	1.264
75	25.08	34.93	23.29	0.350	1.148
100	23.40	35.08	23.90	0.458	1.040
150	21.81	35.26	24.49	0.647	0.851
200	20.41	35.24	24.85	0.814	0.684
250	19.30	35.11	25.05	0.969	0.529
300	16.22	34.64	25.44	1.110	0.388
400	09.95	34.10	26.28	1.334	0.164
500	07.21	34.06	26.67	1.498	0.000

STATION 44

M/V Hugh M. Smith: Cruise 21, 22°06'N, 160°58'W, August 18, 1953. Messenger time: 1128 GCT. Weather: 02, cloud coverage not recorded. Wind: 070°, 12 kt. Sea: 1-3 ft. Wire angle: 08°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.19	35.00	22.99		0.34
15	25.90	35.01	23.09		0.33
31	25.52	34.96	23.17		0.32
62	24.88	34.97	23.37		0.29
93	24.04	35.04	23.68		0.30
124	23.36	35.11	23.92		0.26
154	22.02	35.27	24.44		0.25
207	19.92	35.14	24.91		0.39
259	17.73	34.85	25.24		0.51
309	14.60	34.44	25.65		0.72
361	11.48	34.17	26.06		1.18
413	09.80	34.09	26.30		1.42
515	07.22	34.07	26.68		2.24

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.19	35.00	23.00	0.000	1.498
10	25.99	35.01	23.07	0.048	1.450
20	25.78	35.00	23.12	0.096	1.402
30	25.53	34.96	23.17	0.144	1.354
50	25.20	34.96	23.27	0.237	1.261
75	24.55	34.99	23.49	0.351	1.147
100	23.78	35.06	23.77	0.458	1.040
150	22.24	35.26	24.37	0.653	0.845
200	20.02	35.16	24.90	0.822	0.676
250	18.20	34.91	25.17	0.973	0.525
300	15.41	34.53	25.54	1.109	0.389
400	10.17	34.10	26.24	1.329	0.169
500	07.60	34.07	26.62	1.498	0.000

STATION 45

M/V Hugh M. Smith: Cruise 21, 21°37'N, 160°14'W, August 18, 1953. Messenger time: 1844 GCT. Weather: 80, cloud coverage 3. Wind: 080°, 21 kt. Sea: 3-5 ft. Wire angle: 09°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.87	35.03	23.12		0.33
25	25.70	35.03	23.17		0.32
55	25.02	34.97	23.33		0.27
91	23.00	35.17	24.08		0.27
111	22.46	35.20	24.26		0.31
141	21.82	35.26	24.49		0.25
182	20.28	35.15	24.82		0.40
233	18.37	34.90	25.12		0.49
264	15.70	34.52	25.46		0.83
319	12.54	34.22	25.90		1.21
364	10.69	34.11	26.16		1.55
425	08.46	34.08	26.50		2.06
531	06.78	34.10	26.76		2.46

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.87	35.03	23.12	0.000	1.422
10	25.81	35.03	23.14	0.048	1.374
20	25.74	35.03	23.16	0.095	1.327
30	25.63	35.02	23.18	0.142	1.280
50	25.19	34.98	23.29	0.235	1.187
75	23.88	35.06	23.74	0.346	1.076
100	22.81	35.18	24.14	0.446	0.976
150	21.64	35.26	24.54	0.628	0.794
200	19.60	35.08	24.95	0.792	0.630
250	16.58	34.63	25.35	0.937	0.485
300	13.50	34.30	25.77	1.062	0.360
400	09.18	34.08	26.39	1.264	0.158
500	07.20	34.10	26.70	1.422	0.000

STATION 46

M/V Hugh M. Smith: Cruise 21, 21°09'N, 159°48'W, August 19, 1953. Messenger time: 0053 GCT. Weather: 02, cloud coverage 3. Wind: 070°, 17 kt. Sea: 3-5 ft. Wire angle: 33°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.18	35.08	23.06		0.33
16	26.01	35.05	23.09		0.32
34	25.96	35.05	23.10		0.33
41	25.86	35.07	23.15		0.30
54	23.62	35.06	23.82		0.31
76	22.68	35.12	24.14		0.26
100	21.37	35.13	24.51		0.30
124	20.60	35.10	24.70		0.40
164	19.06	34.96	24.99		0.53
204	16.90	34.66	25.29		0.51
245	15.06	34.43	25.54		0.97
326	11.24	34.14	26.08		1.39
408	08.34	34.06	26.51		2.11

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.18	35.08	23.06	0.000	1.330
10	26.08	35.06	23.07	0.048	1.282
20	26.00	35.05	23.09	0.096	1.234
30	25.99	35.05	23.10	0.144	1.186
50	24.70	35.06	23.50	0.236	1.094
75	22.70	35.12	24.13	0.339	0.991
100	21.37	35.13	24.51	0.430	0.900
150	19.55	35.02	24.91	0.595	0.735
200	17.00	34.67	25.28	0.741	0.589
250	14.82	34.41	25.58	0.873	0.457
300	12.40	34.20	25.91	0.989	0.341
400	08.59	34.06	26.47	1.180	0.150
500	06.80	34.12	26.77	1.330	0.000

STATION 47

M/V Hugh M. Smith: Cruise 21, 20°50'N, 159°13'W, August 19, 1953. Messenger time: 0814 GCT. Weather: 03, cloud coverage not recorded. Wind: 070°, 24 kt. Sea: 5-8 ft. Wire angle: 26°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.05	35.07	23.09		0.30
18	26.04	35.10	23.11		0.31
35	25.78	35.15	23.23		0.26
45	25.52	35.13	23.30		0.26
54	23.34	35.10	23.93		0.27
80	21.89	35.14	24.37		0.26
109	20.48	35.09	24.72		0.36
136	18.99	34.94	25.00		0.49
181	17.08	34.69	25.28		0.70
227	14.92	34.42	25.56		0.93
273	12.36	34.20	25.92		1.26
364	08.68	34.08	26.47		2.01
458	06.84	34.12	26.77		2.60

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D 1000 - \Delta D$ (dyn. m)
00	26.05	35.07	23.09	0.000	1.260
10	26.05	35.08	23.10	0.048	1.212
20	26.03	35.11	23.13	0.096	1.164
30	25.88	35.15	23.21	0.143	1.117
50	23.80	35.10	23.80	0.231	1.029
75	22.18	35.13	24.29	0.329	0.931
100	21.09	35.13	24.59	0.417	0.843
150	18.32	34.85	25.10	0.575	0.685
200	16.41	34.61	25.37	0.715	0.545
250	13.59	34.29	25.74	0.840	0.420
300	11.00	34.13	26.12	0.947	0.313
400	07.89	34.09	26.60	1.122	0.138
500	06.20	34.15	26.88	1.260	0.000

STATION 48

M/V Hugh M. Smith: Cruise 21, 20°21'N, 158°41'W, August 19, 1953. Messenger time: 1620 GCT. Weather: 02, cloud coverage 6. Wind: 080°, 21 kt. Sea: 5-8 ft. Wire angle: 15°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.79	34.91	23.05		0.36
25	25.80	34.90	23.04		0.37
50	25.01	34.83	23.23		0.33
79	24.92	34.85	23.27		0.35
109	24.77	34.86	23.33		0.34
138	22.74	35.10	24.10		0.39
168	20.86	35.07	24.60		0.41
218	17.98	34.77	25.12		0.67
267	15.20	34.46	25.53		0.93
317	12.56	34.21	25.89		1.25
366	10.18	34.09	26.23		1.49
421	08.57	34.05	26.46		1.95
525	06.74	34.14	26.80		2.75

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.79	34.91	23.05	0.000	1.475
10	25.80	34.91	23.05	0.048	1.427
20	25.80	34.90	23.04	0.097	1.378
30	25.42	34.85	23.12	0.145	1.330
50	25.01	34.83	23.23	0.239	1.236
75	24.94	34.85	23.27	0.356	1.119
100	24.81	34.86	23.31	0.471	1.004
150	21.87	35.12	24.37	0.677	0.798
200	19.21	34.90	24.91	0.846	0.629
250	16.20	34.57	25.39	0.991	0.484
300	13.40	34.28	25.77	1.115	0.360
400	09.12	34.05	26.38	1.318	0.157
500	07.14	34.11	26.72	1.475	0.000

STATION 49

M/V Hugh M. Smith: Cruise 21, 19°56'N, 158°11'W, August 19, 1953. Messenger time: 2253 GCT. Weather: 02, cloud coverage 2. Wind: 070°, 16 kt. Sea: 5-8 ft. Wire angle: 20°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.68	34.99	23.14		0.31
32	25.54	35.01	23.20		0.28
61	25.30	35.01	23.28		0.25
91	25.10	35.09	23.40		0.25
120	24.12	35.09	23.70		0.30
135	23.12	35.17	24.05		0.25
149	22.52	35.23	24.27		0.25
200	20.76	35.17	24.71		0.35
249	18.60	35.00	25.14		0.51
300	15.38	34.59	25.59		0.86
349	11.63	34.26	26.10		1.51
401	09.60	34.16	26.38		1.75
499	07.66	34.22	26.73		2.41

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.68	34.99	23.15	0.000	1.504
10	25.61	35.00	23.18	0.047	1.457
20	25.56	35.01	23.20	0.094	1.410
30	25.54	35.01	23.20	0.141	1.363
50	25.49	35.01	23.22	0.235	1.269
75	25.21	35.05	23.34	0.351	1.153
100	25.06	35.10	23.42	0.464	1.040
150	22.47	35.23	24.28	0.670	0.834
200	20.76	35.17	24.71	0.846	0.658
250	18.54	34.99	25.15	1.001	0.503
300	15.38	34.59	25.59	1.136	0.368
400	09.61	34.16	26.38	1.348	0.156
500	07.65	34.22	26.73	1.504	0.000

STATION 50

M/V Hugh M. Smith: Cruise 21, 19°26'N, 157°39'W, August 20, 1953. Messenger time: 0611 GCT. Weather: 02, cloud coverage 8. Wind: 090°, 8 kt. Sea: 5-8 ft. Wire angle: 13°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.79	34.91	23.05		0.37
15	25.80	34.93	23.06		0.39
35	25.81	34.92	23.05		0.40
51	25.27	34.98	23.27		0.39
77	24.87	34.85	23.29		0.39
103	24.27	35.21	23.74		0.28
128	22.74	35.16	24.15		0.31
153	22.34	35.18	24.27		0.35
206	19.84	35.06	24.87		0.50
258	16.60	34.70	25.40		0.76
309	13.54	34.29	25.75		1.20
413	09.04	34.11	26.43		2.00
516	06.91	34.16	26.79		2.70

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.79	34.91	23.05	0.000	1.480
10	25.80	34.92	23.06	0.048	1.432
20	25.80	34.93	23.06	0.096	1.384
30	25.81	34.92	23.05	0.145	1.335
50	25.30	34.98	23.26	0.240	1.240
75	24.90	34.85	23.28	0.356	1.124
100	24.35	35.20	23.71	0.467	1.013
150	22.40	35.18	24.26	0.666	0.814
200	20.00	35.07	24.83	0.839	0.641
250	17.26	34.78	25.30	0.988	0.492
300	14.14	34.36	25.68	1.116	0.364
400	09.42	34.11	26.37	1.323	0.157
500	07.23	34.15	26.74	1.480	0.000

STATION 51

M/V Hugh M. Smith: Cruise 21, 19°01'N, 157°10'W, August 20, 1953. Messenger time: first cast 1231 GCT, second cast 1245 GCT. Weather: 02, cloud coverage 7. Wind: 110°, 27 kt. Sea: 5-8 ft. Wire angle: first cast 30°, second cast 30°. Depth of water: 2000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	24.83	35.08	23.47		0.32
18	24.84	35.14	23.51		0.31
31	24.81	35.13	23.52		0.28
51	22.76	35.12	24.11		0.29
68	21.92	35.07	24.31		0.35
90	21.13	35.06	24.52		0.33
115	20.48	35.07	24.70		0.45
140	19.80	35.03	24.85		0.47
185	18.08	34.79	25.11		0.59
234	15.14	34.43	25.52		0.87
283	11.90	34.21	26.02		1.41
382	08.68	34.13	26.51		2.21
477	06.97	34.17	26.79		2.81

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.83	35.08	23.47	0.000	1.266
10	24.83	35.11	23.50	0.044	1.222
20	24.84	35.14	23.52	0.088	1.178
30	24.81	35.13	23.52	0.132	1.134
50	22.80	35.12	24.10	0.214	1.052
75	21.66	35.06	24.38	0.307	0.959
100	20.86	35.06	24.60	0.394	0.872
150	19.62	35.01	24.89	0.557	0.709
200	17.57	34.71	25.17	0.707	0.559
250	14.26	34.35	25.65	0.839	0.427
300	11.26	34.18	26.11	0.949	0.317
400	08.30	34.13	26.57	1.125	0.141
500	06.60	34.19	26.86	1.266	0.000

STATION 52

M/V Hugh M. Smith: Cruise 21, 18°35'N, 156°34'W, August 20, 1953. Messenger time: 2135 GCT. Weather: 02, cloud coverage 2. Wind: 090°, 14 kt. Sea: 5-8 ft. Wire angle: 26°. Depth of water: 1800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.28	34.94	23.23		0.39
24	25.22	34.93	23.24		0.38
47	25.22	34.96	23.26		0.35
66	24.87	34.98	23.38		0.33
77	23.82	35.07	23.77		0.32
87	23.06	35.08	24.00		0.29
114	21.52	35.11	24.45		0.35
144	20.30	35.03	24.72		0.37
190	18.88	34.93	25.02		0.46
240	16.09	34.53	25.39		0.79
288	12.17	34.18	25.94		1.35
384	08.34	34.08	26.52		2.14
483	06.84	34.18	26.82		2.77

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.28	34.94	23.23	0.000	1.346
10	25.25	34.94	23.24	0.047	1.299
20	25.23	34.93	23.24	0.093	1.253
30	25.22	34.94	23.25	0.140	1.206
50	25.22	34.96	23.27	0.232	1.114
75	23.92	35.06	23.73	0.343	1.003
100	22.33	35.11	24.23	0.442	0.904
150	20.11	35.02	24.77	0.617	0.729
200	18.60	34.90	25.07	0.772	0.574
250	15.30	34.44	25.49	0.911	0.435
300	11.49	34.14	26.04	1.026	0.320
400	08.04	34.09	26.57	1.206	0.140
500	06.66	34.21	26.86	1.346	0.000

STATION 53

M/V Hugh M. Smith: Cruise 21, 18°07'N, 156°02'W, August 21, 1953. Messenger time: 0420 GCT. Weather: 02, cloud coverage 1. Wind: 090°, 19 kt. Sea: 5-8 ft. Wire angle: 19°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.89	34.88	23.30		0.33
30	24.90	34.84	23.27		0.36
60	24.82	34.88	23.32		0.33
81	24.77	34.95	23.39		0.36
100	23.97	34.94	23.62		0.35
120	22.80	35.06	24.06		0.25
151	21.12	34.87	24.38		0.37
200	19.23	34.95	24.94		0.38
250	15.34	34.41	25.46		0.94
302	11.92	34.20	26.00		1.40
353	09.57	34.10	26.34		1.88
403	08.22	34.08	26.54		2.23
503	06.74	34.24	26.88		2.85

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.89	34.88	23.31	0.000	1.408
10	24.89	34.87	23.30	0.046	1.362
20	24.90	34.86	23.29	0.092	1.316
30	24.90	34.84	23.27	0.138	1.270
50	24.85	34.86	23.30	0.230	1.178
75	24.78	34.94	23.38	0.345	1.063
100	23.97	34.94	23.63	0.455	0.953
150	21.13	34.87	24.38	0.653	0.755
200	19.23	34.95	24.94	0.821	0.587
250	15.34	34.41	25.46	0.963	0.445
300	12.00	34.20	25.99	1.081	0.327
400	08.30	34.08	26.53	1.265	0.143
500	06.79	34.23	26.86	1.408	0.000

STATION 54

M/V Hugh M. Smith: Cruise 21, 17°39'N, 155°31'W, August 21, 1953. Messenger time: 1234 GCT. Weather: 02, cloud coverage 4. Wind: 080°, 17 kt. Sea: 3-5 ft. Wire angle: 20°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.01	34.99	23.35		0.31
25	25.04	34.99	23.34		0.29
50	24.99	35.05	23.40		0.31
73	23.26	35.16	24.00		0.24
94	22.19	35.17	24.31		0.31
115	21.92	35.20	24.41		0.26
142	20.54	35.21	24.79		0.34
193	18.29	34.94	25.17		0.51
239	15.14	34.45	25.54		0.95
290	11.78	34.23	26.05		1.47
342	09.98	34.25	26.39		2.21
391	09.33	34.30	26.54		2.51
487	07.12	34.25	26.83		2.81

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.01	34.99	23.35	0.000	1.305
10	25.02	34.99	23.35	0.045	1.260
20	25.03	34.99	23.35	0.091	1.214
30	25.03	35.00	23.35	0.136	1.169
50	24.99	35.05	23.40	0.227	1.078
75	23.16	35.16	24.03	0.332	0.973
100	22.10	35.18	24.35	0.427	0.878
150	20.20	35.19	24.87	0.596	0.709
200	18.01	34.89	25.20	0.745	0.560
250	14.40	34.36	25.63	0.877	0.428
300	11.31	34.22	26.13	0.987	0.318
400	09.18	34.30	26.56	1.163	0.142
500	06.80	34.23	26.86	1.305	0.000

STATION 55

M/V Hugh M. Smith: Cruise 21, 17°19'N, 156°12'W, August 21, 1953. Messenger time: 1855 GCT. Weather: 02, cloud coverage 5. Wind: 060°, 16 kt. Sea: 5-8 ft. Wire angle: 19°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.99	34.88	23.27		0.43
27	25.00	34.88	23.27		0.46
56	25.02	34.96	23.32		0.38
67	24.55	34.89	23.41		0.41
76	24.48	34.94	23.47		0.37
92	23.64	34.88	23.68		0.33
123	21.90	35.07	24.32		0.38
152	21.14	34.98	24.46		0.36
205	18.82	34.93	25.03		0.52
256	14.82	34.42	25.58		1.08
305	11.36	34.16	26.07		1.66
407	08.28	34.25	26.66		2.57
508	06.37	34.21	26.90		2.94

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.99	34.88	23.27	0.000	1.375
10	25.00	34.88	23.27	0.046	1.329
20	25.00	34.88	23.27	0.092	1.283
30	25.00	34.88	23.27	0.139	1.236
50	25.02	34.94	23.31	0.231	1.144
75	24.50	34.94	23.47	0.344	1.031
100	23.15	34.91	23.84	0.451	0.924
150	21.10	34.98	24.47	0.642	0.733
200	19.00	34.93	24.99	0.806	0.569
250	15.42	34.48	25.50	0.947	0.428
300	11.61	34.16	26.03	1.062	0.313
400	08.41	34.24	26.64	1.239	0.136
500	06.49	34.22	26.89	1.375	0.000

STATION 56

M/V Hugh M. Smith: Cruise 21, 17°45'N, 156°40'W, August 22, 1953. Messenger time: 0055 GCT. Weather: 02, cloud coverage 2. Wind: 070°, 13 kt. Sea: 3-5 ft. Wire angle: 13°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.13	34.89	23.24		0.37
26	25.04	34.86	23.24		0.37
55	24.97	34.88	23.28		0.39
71	24.06	34.88	23.55		0.29
87	23.46	34.96	23.79		0.29
102	22.84	35.13	24.10		0.27
122	21.49	34.97	24.36		0.34
122	21.49	35.12	24.47		-
153	20.46	35.08	24.72		0.40
202	18.56	34.86	25.04		0.56
255	15.73	34.50	25.44		0.80
306	12.01	34.16	25.96		1.43
408	08.99	34.19	26.51		2.26
511	06.50	34.17	26.85		2.91

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.13	34.89	23.24	0.000	1.386
10	25.09	34.88	23.24	0.046	1.340
20	25.06	34.87	23.25	0.093	1.293
30	25.02	34.87	23.26	0.139	1.247
50	24.99	34.88	23.27	0.232	1.154
75	23.68	34.91	23.69	0.343	1.043
100	23.00	35.11	24.04	0.445	0.941
150	20.60	35.08	24.68	0.626	0.760
200	18.68	34.88	25.03	0.784	0.602
250	16.00	34.53	25.41	0.926	0.460
300	12.37	34.18	25.90	1.047	0.339
400	09.20	34.19	26.47	1.238	0.148
500	06.76	34.18	26.83	1.386	0.000

STATION 57

M/V Hugh M. Smith: Cruise 21, 18°13'N, 157°09'W, August 22, 1953. Messenger time: 0755 GCT. Weather: 02, cloud coverage 3. Wind: 070°, 15 kt. Sea: 3-5 ft. Wire angle: 26°. Depth of water: 1700 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.87	34.89	23.01		0.36
22	25.70	34.96	23.12		0.35
44	25.12	35.06	23.37		0.27
65	23.75	35.25	23.93		0.22
92	22.45	35.20	24.26		0.29
114	21.46	35.17	24.52		0.31
141	20.58	35.08	24.69		0.40
159	19.19	34.96	24.96		0.52
186	17.94	34.86	25.20		0.68
186	-	-	-		0.56
223	15.52	34.53	25.51		0.86
260	13.38	34.29	25.78		1.17
332	09.67	34.13	26.35		1.94
406	07.78	34.14	26.65		2.46

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.87	34.89	23.01	0.000	1.302
10	25.80	34.92	23.06	0.048	1.254
20	25.71	34.95	23.11	0.096	1.206
30	25.59	34.98	23.17	0.144	1.158
50	24.91	35.10	23.47	0.236	1.066
75	23.08	35.22	24.10	0.340	0.962
100	22.21	35.19	24.32	0.433	0.869
150	19.92	35.02	24.82	0.604	0.698
200	17.00	34.75	25.34	0.752	0.550
250	13.98	34.35	25.71	0.879	0.423
300	11.22	34.16	26.10	0.987	0.315
400	07.90	34.14	26.63	1.161	0.141
500	06.80	34.14	26.79	1.302	0.000

STATION 58

M/V Hugh M. Smith: Cruise 21, 18°47'N, 157°46'W, August 22, 1953. Messenger time: 1617 GCT. Weather: 02, cloud coverage 3. Wind: 100, 11 kt. Sea: 1-3 ft. Wire angle: 07°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.77	34.82	22.99		0.44
10	25.77	34.88	23.04		0.38
33	25.34	34.88	23.17		0.35
65	24.92	34.86	23.28		0.39
98	24.58	34.83	23.36		0.36
112	23.25	35.01	23.89		0.33
128	21.85	35.14	24.38		0.34
161	20.27	35.19	24.85		0.43
213	18.42	34.97	25.16		0.56
267	15.76	34.52	25.45		0.83
320	12.48	34.15	25.86		1.21
428	07.85	34.09	26.60		2.39
534	06.52	34.08	26.78		2.84

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.77	34.82	22.99	0.000	1.442
10	25.77	34.88	23.04	0.049	1.393
20	25.50	34.88	23.12	0.097	1.345
30	25.34	34.88	23.17	0.144	1.298
50	25.10	34.87	23.23	0.238	1.204
75	24.81	34.84	23.30	0.354	1.088
100	24.54	34.83	23.37	0.469	0.973
150	20.80	35.20	24.72	0.665	0.777
200	18.98	35.05	25.08	0.821	0.621
250	17.02	34.73	25.32	0.964	0.478
300	13.61	34.25	25.71	1.091	0.351
400	08.60	34.09	26.49	1.291	0.151
500	06.90	34.08	26.73	1.442	0.000

STATION 59

M/V Hugh M. Smith: Cruise 21, 19°13'N, 158°20'W, August 22, 1953. Messenger time: 2212 GCT. Weather: 02, cloud coverage 2. Wind: 120°, 5 kt. Sea: < 1 ft. Wire angle: 13°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.00	34.95	23.02		0.41
10	25.86	34.96	23.07		0.37
23	25.53	34.92	23.14		0.37
40	25.34	34.93	23.21		0.40
60	24.96	34.88	23.29		0.40
89	24.65	34.89	23.38		0.39
119	23.79	34.98	23.71		0.35
148	22.30	35.20	24.30		0.36
199	19.73	35.09	24.92		0.47
247	16.98	34.73	25.33		0.80
298	12.84	34.34	25.93		1.39
398	09.22	34.32	26.57		2.46
498	07.34	34.25	26.80		2.82

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.00	34.95	23.02	0.000	1.433
10	25.86	34.96	23.07	0.048	1.385
20	25.65	34.93	23.11	0.096	1.337
30	25.42	34.92	23.17	0.144	1.289
50	25.22	34.92	23.24	0.238	1.195
75	24.78	34.88	23.34	0.353	1.080
100	24.52	34.90	23.43	0.467	0.966
150	22.20	35.20	24.33	0.671	0.762
200	19.68	35.09	24.93	0.840	0.593
250	16.65	34.69	25.38	0.984	0.449
300	12.78	34.34	25.94	1.105	0.328
400	09.19	34.32	26.58	1.290	0.143
500	07.30	34.25	26.81	1.433	0.000

STATION 60

M/V Hugh M. Smith: Cruise 21, 19°38'N, 158°52'W, August 23, 1953. Messenger time: 0508 GCT. Weather: 02, cloud coverage 1. Wind: Light and variable. Sea: < 1 ft. Wire angle: 07°. Depth of water: 2000 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.05	34.88	22.95		0.42
15	25.38	34.96	23.21		0.28
35	25.08	34.94	23.29		0.25
55	24.96	34.95	23.33		0.21
75	24.70	34.93	23.40		0.37
100	24.53	34.99	23.50		0.29
132	23.55	35.06	23.84		0.30
156	22.42	35.26	24.31		0.31
188	20.95	35.26	24.72		0.36
246	17.84	34.96	25.30		0.61
306	13.20	-	-		-
409	09.34	34.38	26.62		2.47
512	07.18	34.39	26.94		3.09

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.05	34.88	22.95	0.000	1.434
10	25.45	34.95	23.19	0.048	1.386
20	25.29	34.96	23.24	0.095	1.339
30	25.13	34.94	23.28	0.141	1.293
50	25.00	34.95	23.32	0.233	1.201
75	24.70	34.93	23.40	0.347	1.087
100	24.53	34.99	23.50	0.459	0.975
150	22.80	35.18	24.15	0.666	0.768
200	20.41	35.23	24.85	0.841	0.593
250	17.50	34.92	25.35	0.989	0.445
300	13.55	34.59	25.98	1.109	0.325
400	09.60	34.38	26.56	1.294	0.140
500	07.38	34.39	26.91	1.434	0.000

STATION 61

M/V Hugh M. Smith: Cruise 21, 20°05'N, 159°15'W, August 23, 1953. Messenger time: 1045 GCT. Weather: 02, cloud coverage 3. Wind: 050°, 9 kt. Sea: 1-3 ft. Wire angle: 07°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.30	34.98	22.94		0.37
20	26.12	34.97	22.99		0.33
51	26.00	34.93	23.00		0.40
84	25.80	35.09	23.18		0.38
104	24.51	35.07	23.56		0.37
125	22.74	35.07	24.08		0.39
155	21.49	35.13	24.48		0.32
208	19.20	35.03	25.01		0.51
260	14.69	34.44	25.63		1.10
313	11.26	34.23	26.15		1.81
365	09.46	34.14	26.39		1.88
417	08.03	34.11	26.59		2.13
521	06.33	34.13	26.84		2.93

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.30	34.98	22.95	0.000	1.434
10	26.24	34.98	22.96	0.049	1.385
20	26.12	34.97	22.99	0.098	1.336
30	26.10	34.96	22.99	0.147	1.287
50	26.01	34.93	23.00	0.245	1.189
75	25.87	34.98	23.08	0.367	1.067
100	24.67	35.07	23.51	0.482	0.952
150	21.68	35.13	24.43	0.682	0.752
200	19.61	35.06	24.93	0.849	0.585
250	15.65	34.54	25.49	0.991	0.443
300	12.00	34.27	26.04	1.106	0.328
400	08.45	34.11	26.53	1.288	0.146
500	06.68	34.12	26.79	1.434	0.000

STATION 62

M/V Hugh M. Smith: Cruise 21, 20°31'N, 159°49'W, August 23, 1953. Messenger time: 1724 GCT. Weather: 02, cloud coverage 3. Wind: 090°, 8 kt. Sea: < 1 ft. Wire angle: 07°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
03	26.08	35.14	23.14		0.38
24	26.00	35.15	23.17		0.40
44	25.94	35.15	23.19		0.36
65	24.02	35.12	23.75		0.34
86	22.78	35.20	24.17		0.34
107	22.11	35.22	24.37		0.35
127	20.94	35.19	24.67		0.36
158	19.00	35.02	25.05		0.55
209	15.50	34.57	25.55		0.90
261	12.02	34.26	26.03		1.24
313	10.23	34.18	26.29		1.76
416	07.75	34.11	26.63		2.34
519	06.47	34.19	26.87		2.90

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.08	35.14	23.14	0.000	1.276
10	26.08	35.14	23.14	0.047	1.229
20	26.05	35.15	23.15	0.095	1.181
30	25.99	35.15	23.17	0.142	1.134
50	25.90	35.15	23.20	0.236	1.040
75	23.30	35.15	23.98	0.345	0.931
100	22.38	35.22	24.30	0.440	0.836
150	19.52	35.07	24.96	0.609	0.667
200	15.95	34.62	25.49	0.749	0.527
250	12.42	34.28	25.97	0.866	0.410
300	10.68	34.20	26.23	0.965	0.311
400	08.05	34.11	26.59	1.135	0.141
500	06.69	34.17	26.83	1.276	0.000

STATION 63

M/V Hugh M. Smith: Cruise 21, 20°49'N, 160°27'W, August 24, 1953. Messenger time: 0019 GCT. Weather: 02, cloud coverage 4. Wind: 080°, 16 kt. Sea: 1-3 ft. Wire angle: 10°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.43	35.11	23.00		0.37
22	26.00	35.09	23.12		0.36
48	25.83	35.05	23.14		0.29
66	23.99	35.12	23.75		0.30
85	23.04	35.22	24.11		0.29
105	22.26	35.26	24.36		0.30
126	21.38	35.22	24.57		0.41
155	20.10	35.14	24.86		0.50
206	17.06	34.75	25.33		0.72
257	14.34	34.43	25.69		0.99
312	11.53	34.19	26.07		1.61
412	08.46	34.09	26.51		2.17

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.43	35.11	23.00	0.000	1.345
10	26.05	35.09	23.11	0.048	1.297
20	26.00	35.09	23.12	0.096	1.249
30	25.99	35.09	23.13	0.144	1.201
50	25.50	35.04	23.24	0.238	1.107
75	23.57	35.16	23.91	0.347	0.998
100	22.50	35.26	24.29	0.443	0.902
150	20.35	35.15	24.80	0.615	0.730
200	17.12	34.75	25.31	0.764	0.581
250	14.80	34.48	25.63	0.893	0.452
300	12.01	34.22	26.00	1.006	0.339
400	08.77	34.10	26.47	1.192	0.153
500	07.10	34.10	26.72	1.345	0.000

STATION 64

M/V Hugh M. Smith: Cruise 21, 21°24'N, 160°59'W, August 24, 1953. Messenger time: 0655 GCT. Weather: 02, cloud coverage 7. Wind: 090°, 11 kt. Sea: 1-3 ft. Wire angle: 13°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.40	35.09	23.00		0.34
14	26.23	35.10	23.05		0.30
30	25.77	35.06	23.18		0.31
50	25.41	35.02	23.25		0.28
70	24.90	35.06	23.44		0.28
91	24.05	35.06	23.69		0.28
121	22.58	35.16	24.20		0.34
152	21.97	35.28	24.46		0.33
202	20.40	35.26	24.87		0.39
252	16.16	34.65	25.46		0.73
303	12.78	34.30	25.91		1.22
403	09.62	34.13	26.35		1.82
504	07.42	34.13	26.69		2.54

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.40	35.09	23.00	0.000	1.445
10	26.35	35.09	23.01	0.049	1.396
20	26.01	35.08	23.11	0.097	1.348
30	25.77	35.06	23.17	0.144	1.301
50	25.41	35.02	23.25	0.238	1.207
75	24.70	35.06	23.50	0.352	1.093
100	23.62	35.07	23.83	0.459	0.986
150	22.00	35.27	24.44	0.650	0.795
200	20.55	35.28	24.85	0.819	0.626
250	16.50	34.69	25.41	0.965	0.480
300	12.92	34.31	25.89	1.086	0.359
400	09.70	34.13	26.34	1.284	0.161
500	07.51	34.13	26.68	1.445	0.000

STATION 65

M/V Hugh M. Smith: Cruise 21, 21°46'N, 161°27'W, August 24, 1953. Messenger time: 1310 GCT. Weather: 02, cloud coverage 5. Wind: 060°, 9 kt. Sea: 1-3 ft. Wire angle: 02°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.29	35.06	23.01		0.40
10	26.31	35.08	23.02		0.39
27	26.18	35.07	23.05		0.29
42	26.07	35.06	23.07		0.30
63	25.28	35.00	23.27		0.34
94	23.81	35.15	23.83		0.29
125	22.91	35.21	24.14		0.31
155	22.05	35.35	24.48		0.25
206	20.10	35.24	24.93		0.39
258	17.66	34.88	25.28		0.46
309	14.38	34.43	25.68		0.87
413	09.84	34.14	26.33		1.58
514	07.34	34.08	26.67		2.51

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.29	35.06	23.01	0.000	1.486
10	26.31	35.08	23.02	0.049	1.437
20	26.20	35.07	23.04	0.097	1.389
30	26.14	35.07	23.06	0.145	1.341
50	25.75	35.03	23.15	0.241	1.245
75	24.52	35.05	23.54	0.355	1.131
100	23.60	35.16	23.90	0.461	1.025
150	22.22	35.33	24.43	0.651	0.835
200	20.34	35.27	24.90	0.819	0.667
250	18.14	34.95	25.22	0.968	0.518
300	14.88	34.49	25.62	1.101	0.385
400	10.34	34.15	26.25	1.317	0.169
500	07.67	34.08	26.62	1.486	0.000

STATION 66

M/V Hugh M. Smith: Cruise 21, 21°49'N, 157°33'W, August 26, 1953. Messenger time: 0119 GCT. Weather: 02, cloud coverage 3. Wind: 090°, 23 kt. Sea: 5-8 ft. Wire angle: 19°. Depth of water: 1500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.40	35.00	23.24		0.32
20	25.40	35.02	23.25		0.29
46	25.34	35.02	23.27		0.30
61	25.06	35.12	23.43		0.27
77	24.38	35.23	23.72		0.22
92	23.40	35.34	24.10		0.20
121	22.10	35.26	24.41		0.30
151	21.22	35.31	24.69		0.32
202	20.04	35.22	24.94		0.34
251	16.80	34.81	25.43		0.55
302	14.96	34.49	25.61		0.71
402	09.52	34.11	26.36		1.65
502	07.34	34.13	26.71		2.37

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.40	35.00	23.24	0.000	1.430
10	25.40	35.01	23.25	0.046	1.384
20	25.40	35.02	23.26	0.093	1.337
30	25.39	35.02	23.26	0.139	1.291
50	25.30	35.03	23.29	0.232	1.198
75	24.48	35.20	23.67	0.343	1.087
100	23.08	35.31	24.17	0.443	0.987
150	21.29	35.30	24.66	0.622	0.808
200	20.12	35.22	24.92	0.784	0.646
250	16.82	34.81	25.43	0.927	0.503
300	15.02	34.49	25.59	1.056	0.374
400	09.61	34.10	26.34	1.269	0.161
500	07.39	34.12	26.69	1.430	0.000

STATION 67

M/V Hugh M. Smith: Cruise 21, 21°22'N, 157°33'W, August 26, 1953. Messenger time: 0603 GCT. Weather: 03, cloud coverage 3. Wind: 090°, 23 kt. Sea: 5-8 ft. Wire angle: 19°. Depth of water: 350 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.26	34.94	23.24		0.35
24	25.27	34.90	23.20		0.34
48	25.23	34.96	23.26		0.33
67	24.41	34.99	23.53		0.25
91	23.50	34.97	23.79		0.27
117	22.39	35.10	24.20		0.30
143	21.46	35.21	24.55		0.27
168	20.96	35.17	24.65		0.28
201	20.40	35.20	24.82		0.34
235	19.90	35.10	24.88		0.33
292	17.15	34.62	25.21		0.56
399	09.86	34.10	26.29		1.85
501	06.98	34.01	26.66		2.75

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.26	34.94	23.24	0.000	1.502
10	25.26	34.93	23.23	0.047	1.455
20	25.27	34.91	23.21	0.093	1.409
30	25.26	34.92	23.22	0.140	1.362
50	25.20	34.97	23.28	0.233	1.269
75	23.98	34.97	23.65	0.344	1.158
100	23.31	34.98	23.85	0.449	1.053
150	21.30	35.21	24.59	0.637	0.865
200	20.41	35.20	24.82	0.802	0.700
250	19.50	35.01	24.92	0.961	0.541
300	16.60	34.56	25.29	1.109	0.393
400	09.80	34.10	26.30	1.338	0.164
500	07.00	34.01	26.66	1.502	0.000

STATION 68

M/V Hugh M. Smith: Cruise 21, 21°02'N, 157°32'W, August 26, 1953. Messenger time: 1014 GCT. Weather: 02, cloud coverage 2. Wind: 050°, 24 kt. Sea: 3-5 ft. Wire angle: 02°. Depth of water: 30 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.61	34.88	23.08		0.32
09	25.62	34.90	23.09		0.33
19	25.60	34.92	23.12		0.31
35	24.78	34.88	23.34		0.30

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)

STATION 69

M/V Hugh M. Smith: Cruise 21, 20°33'N, 157°29'W, August 26, 1953. Messenger time: 1535 GCT. Weather: 02, cloud coverage 1. Wind: 080°, 9 kt. Sea: 5-8 ft. Wire angle: 05°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.90	34.93	23.03		0.27
21	25.88	34.91	23.02		0.27
38	25.01	34.90	23.28		0.27
58	24.54	34.92	23.44		0.26
78	23.43	34.97	23.81		0.25
105	22.58	-	-		0.25
131	21.46	35.07	24.44		0.33
157	20.68	34.99	24.59		0.44
210	18.78	34.90	25.02		0.51
261	16.21	34.48	25.32		0.68
313	12.73	34.11	25.77		1.18
415	08.80	33.95	26.35		1.95
519	06.76	34.03	26.71		2.72

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.90	34.93	23.03	0.000	1.453
10	25.89	34.92	23.03	0.048	1.405
20	25.88	34.91	23.02	0.097	1.356
30	25.40	34.90	23.16	0.145	1.308
50	24.71	34.91	23.38	0.238	1.215
75	23.62	34.96	23.74	0.347	1.106
100	22.85	35.01	24.00	0.448	1.005
150	20.99	35.02	24.53	0.634	0.819
200	19.20	34.92	24.93	0.798	0.655
250	16.80	34.58	25.26	0.946	0.507
300	13.60	34.18	25.66	1.076	0.377
400	09.21	33.95	26.28	1.288	0.165
500	07.09	34.02	26.66	1.453	0.000

STATION 5 [1/]

M/V Hugh M. Smith: Cruise 26, 20°33'N, 157°44'W, May 29, 1954. Messenger time: 1623 GCT. Weather: 02, cloud coverage 9. Wind: 070, 19 kt. Sea: 3-5 ft. Wire angle: 25°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.80	34.94	23.38		
23	24.76	34.94	23.39		
51	23.50	-	-		
103	20.62	35.08	24.68		
132	20.19	35.08	24.79		
159	19.60	35.05	24.92		
206	18.21	-	-		
310	11.32	34.16	26.08		
417	08.26	-	-		
522	06.88	34.22	26.84		
1007	05.15	34.38	27.19		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.80	34.94	23.38	0.000	1.860
10	24.78	34.94	23.38	0.045	1.814
20	24.77	34.94	23.39	0.090	1.769
30	24.73	34.94	23.40	0.135	1.724
50	23.58	35.14	23.89	0.221	1.639
75	22.18	35.19	24.33	0.317	1.543
100	20.72	35.09	24.66	0.404	1.456
150	19.89	35.07	24.86	0.567	1.293
200	18.43	34.92	25.12	0.719	1.140
250	15.14	34.53	25.60	0.854	1.005
300	11.85	34.16	25.98	0.969	0.890
400	08.65	34.20	26.57	1.153	0.707
500	07.17	34.21	26.80	1.298	0.562
600	06.36	34.26	26.94	1.426	0.434
700	05.90	34.30	27.03	1.543	0.316
800	05.52	34.34	27.11	1.652	0.207
1000	05.18	34.38	27.19	1.860	0.000

1/ Hugh M. Smith cruise 26 was primarily a skipjack scouting cruise and, therefore, hydrographic observations, which started with station 5, were designated by odd numbers.

STATION 7

M/V Hugh M. Smith: Cruise 26, 19°45'N, 156°18'W, May 30, 1954. Messenger time: 1605 GCT. Weather: 02, cloud coverage 2. Wind: 290°, 11 kt. Sea: 1-3 ft. Wire angle: 17°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.48	-	-	4.56	
00	-	-	-	4.91	
09	25.48	34.69	22.98	5.30	
38	24.12	34.97	23.60	4.99	
38	-	-	-	4.74	
75	22.92	35.25	24.17	4.90	
113	22.00	-	-	4.65	
151	20.10	35.01	24.76	4.62	
195	18.66	34.92	25.06	4.38	
289	11.37	34.14	26.06	3.73	
389	08.60	34.18	26.56	2.49	
484	07.20	34.22	26.80	1.33	
484	07.14	-	26.81	-	
585	06.24	34.29	26.98	0.76	
772	05.14	34.45	27.24	0.77	
969	04.56	34.49	27.33	1.17	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.48	34.69	22.98	0.000	1.815
10	25.48	34.69	22.98	0.049	1.766
20	25.43	34.70	23.00	0.098	1.717
30	24.60	34.87	23.38	0.145	1.670
50	23.53	35.13	23.90	0.230	1.585
75	22.92	35.25	24.17	0.329	1.486
100	22.32	35.23	24.32	0.424	1.391
150	20.21	35.02	24.74	0.597	1.218
200	18.63	34.91	25.06	0.754	1.061
250	14.48	34.43	25.66	0.889	0.926
300	10.84	34.13	26.15	0.998	0.817
400	08.42	34.18	26.59	1.173	0.642
500	07.00	34.22	26.83	1.315	0.500
600	06.10	34.31	27.02	1.438	0.377
700	05.45	34.41	27.18	1.545	0.270
800	05.03	34.46	27.27	1.640	0.175
1000	04.45	34.49	27.36	1.815	0.000

STATION 9

M/V Hugh M. Smith: Cruise 26, 19°47'N, 157°23'W, June 2, 1954. Messenger time: 1610 GCT. Weather: 02, cloud coverage 6. Wind: 050°, 21 kt. Sea: 8-12 ft. Wire angle: 20°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	24.28	35.05	23.62	5.00	
24	24.28	35.07	23.63	4.91	
53	22.04	35.17	24.35	5.05	
87	20.34	35.03	24.71	4.83	
126	17.87	34.83	25.19	4.35	
165	15.55	34.52	25.50	4.42	
213	12.87	34.27	25.87	3.86	
322	08.78	34.20	26.55	2.63	
434	06.89	34.27	26.88	1.25	
541	06.06	34.34	27.05	0.86	
648	05.60	34.40	27.15	0.83	
859	04.68	34.51	27.35	0.89	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	24.28	35.05	23.62	0.000	
10	24.28	35.05	23.62	0.043	
20	24.28	35.06	23.59	0.086	
30	23.30	35.15	23.98	0.127	
50	22.25	35.18	24.30	0.203	
75	20.90	35.06	24.59	0.291	
100	19.77	34.99	24.83	0.373	
150	16.85	34.70	25.34	0.520	
200	13.39	34.31	25.80	0.644	
250	11.25	34.16	26.09	0.751	
300	09.37	34.18	26.44	0.842	
400	07.32	34.24	26.80	0.992	
500	06.32	34.31	26.99	1.122	
600	05.78	34.38	27.11	1.237	
700	05.39	34.43	27.20	1.337	
800	04.90	34.49	27.31	1.429	

STATION 11

M/V Hugh M. Smith: Cruise 26, 19°51'N, 158°43'W, June 3, 1954. Messenger time: 1556 GCT. Weather: 02, cloud coverage 6. Wind: 080°, 18 kt. Sea: 3-5 ft. Wire angle: 13°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.17	34.76	23.13	4.80	
11	25.17	34.76	23.13	4.83	
26	24.98	34.81	23.22	4.83	
57	24.20	35.07	23.65	4.88	
115	22.66	35.30	24.28	4.89	
171	20.57	35.26	24.82	4.72	
228	17.74	34.79	25.19	4.45	
343	10.22	34.18	26.29	3.18	
464	07.66	34.31	26.80	1.25	
580	06.41	34.31	26.98	0.95	
580	06.36	-	26.98	-	
694	05.69	34.42	27.15	0.71	
917	04.74	34.47	27.31	0.77	
1069	04.40	34.51	27.38	0.96	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.17	34.76	23.13	0.000	1.871
10	25.17	34.76	23.13	0.048	1.824
20	25.10	34.77	23.16	0.095	1.776
30	24.98	34.81	23.22	0.142	1.729
50	24.38	35.02	23.56	0.232	1.639
75	23.81	35.15	23.83	0.338	1.533
100	22.83	35.29	24.22	0.436	1.434
150	21.60	35.32	24.59	0.616	1.255
200	19.59	35.10	24.96	0.779	1.092
250	16.21	34.58	25.40	0.923	0.948
300	12.03	34.22	26.00	1.043	0.828
400	08.78	34.26	26.59	1.224	0.647
500	07.22	34.31	26.87	1.365	0.506
600	06.27	34.32	27.00	1.487	0.384
700	05.66	34.42	27.16	1.595	0.276
800	05.20	34.45	27.24	1.693	0.178
1000	04.54	34.50	27.35	1.871	0.000

STATION 13

M/V Hugh M. Smith: Cruise 26, 18°12'N, 158°51'W, June 4, 1954. Messenger time: 1545 GCT. Weather: 02, cloud coverage 4. Wind: 070°, 18 kt. Sea: 5-8 ft. Wire angle: 25°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.39	34.70	23.02	4.87	
37	25.41	34.70	23.01	4.84	
73	24.26	34.92	23.53	5.08	
114	22.73	35.26	24.23	5.00	
155	21.80	35.34	24.55	4.83	
201	19.61	35.07	24.93	4.58	
302	11.71	34.20	26.04	3.90	
408	08.88	34.33	26.63	1.80	
510	07.71	34.40	26.87	0.78	
613	06.74	34.43	27.03	0.59	
816	05.40	34.47	27.23	0.82	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.39	34.70	23.02	0.000	
10	25.39	34.70	23.02	0.049	
20	25.39	34.70	23.02	0.097	
30	25.40	34.70	23.01	0.146	
50	25.16	34.74	23.12	0.242	
75	24.20	34.93	23.55	0.357	
100	23.12	35.19	24.07	0.461	
150	21.92	35.34	24.52	0.646	
200	19.87	35.10	24.89	0.812	
250	15.42	34.50	25.52	0.955	
300	11.73	34.20	26.04	1.071	
400	09.03	34.33	26.61	1.250	
500	07.82	34.39	26.84	1.391	
600	06.87	34.43	27.01	1.514	
700	06.06	34.45	27.13	1.624	
800	05.44	34.47	27.22	1.724	

STATION 15

M/V Hugh M. Smith: Cruise 26, 16°16'N, 160°28'W, June 5, 1954. Messenger time: 1555 GCT. Weather: 02, cloud coverage 4. Wind: 080°, 15 kt. Sea: 3-5 ft. Wire angle: 33°. Depth of water: 3100 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.56	34.72	22.98	4.68	
26	25.56	34.70	22.96	4.68	
51	24.98	34.65	23.10	4.81	
76	23.42	34.96	23.80	4.91	
110	22.16	35.23	24.37	4.74	
144	20.27	35.01	24.72	4.54	
178	18.29	34.83	25.09	4.25	
259	11.21	34.31	26.22	2.59	
349	09.22	34.38	26.62	1.49	
434	07.84	34.36	26.82	1.01	
525	07.01	34.38	26.95	0.69	
563	07.12	34.43	26.98	0.82	
877	04.86	34.52	27.33	0.77	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.56	34.72	22.98	0.000	
10	25.56	34.72	22.98	0.049	
20	25.56	34.71	22.97	0.098	
30	25.57	34.71	22.97	0.147	
50	25.02	34.65	23.09	0.244	
75	23.43	34.95	23.79	0.356	
100	22.30	35.22	24.32	0.454	
150	20.08	34.98	24.74	0.628	
200	15.00	34.46	25.57	0.772	
250	11.90	34.31	26.09	0.884	
300	10.29	34.33	26.40	0.977	
400	08.27	34.36	26.75	1.131	
500	07.21	34.37	26.92	1.262	
600	06.50	34.41	27.04	1.379	
700	05.87	34.46	27.16	1.486	
800	05.27	34.50	27.27	1.582	

STATION 17

M/V Hugh M. Smith: Cruise 26, 14°56'N, 162°16'W, June 6, 1954. Messenger time: 1551 GCT. Weather: 15, cloud coverage 5. Wind: 080°, 19 kt. Sea: 3-5 ft. Wire angle: 20°. Depth of water: 3800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.51	34.52	22.53	4.66	
55	26.49	34.51	22.53	4.66	
95	24.76	34.99	23.43	4.79	
135	23.88	35.23	23.87	4.73	
174	22.72	35.25	24.23	4.60	
219	18.56	34.88	25.06	4.16	
330	10.00	34.22	26.36	2.98	
444	07.96	34.34	26.78	1.14	
554	06.87	34.43	27.01	0.64	
664	06.00	34.47	27.16	0.62	
664	05.95	-	27.16	-	
879	04.90	34.45	27.27	0.82	
1094	04.27	34.54	27.41	1.11	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.51	34.52	22.53	0.000	1.964
10	26.51	34.52	22.53	0.053	1.911
20	26.51	34.52	22.53	0.106	1.857
30	26.50	34.52	22.53	0.160	1.804
50	26.50	34.51	22.53	0.266	1.697
75	25.25	34.86	23.17	0.395	1.569
100	24.62	35.05	23.52	0.513	1.451
150	23.59	35.25	23.97	0.724	1.240
200	21.25	35.14	24.55	0.912	1.052
250	14.30	34.50	25.76	1.057	0.907
300	11.29	34.26	26.16	1.164	0.800
400	08.49	34.29	26.66	1.334	0.630
500	07.39	34.39	26.91	1.470	0.494
600	06.47	34.46	27.09	1.586	0.378
700	05.72	34.46	27.18	1.689	0.275
800	05.21	34.45	27.24	1.785	0.178
1000	04.53	34.50	27.35	1.964	0.000

STATION 19

M/V Hugh M. Smith: Cruise 26, 13°54'N, 164°01'W, June 7, 1954. Messenger time: 1542 GCT. Weather: 02, cloud coverage 2. Wind: 080°, 21 kt. Sea: 8-12 ft. Wire angle: 26°. Depth of water: 2800 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.03	34.54	22.38	4.70	
38	27.04	34.60	22.43	4.77	
76	24.56	34.99	23.49	5.09	
119	23.04	35.32	24.18	4.73	
162	20.86	35.16	24.67	4.48	
210	16.71	34.69	25.36	4.04	
210	16.79	-	25.34	-	
316	10.49	34.47	26.47	1.00	
426	08.88	34.60	26.84	0.49	
533	07.66	34.60	27.03	1.06	
640	06.88	34.52	27.08	0.85	
851	05.53	34.56	27.28	1.16	
1065	04.45	34.60	27.44	1.03	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	27.03	34.54	22.39	0.000	1.838
10	27.03	34.54	22.39	0.055	1.783
20	27.03	34.57	22.41	0.109	1.729
30	27.04	34.59	22.42	0.164	1.674
50	25.92	34.79	22.92	0.268	1.570
75	24.60	34.98	23.47	0.386	1.452
100	23.72	35.20	23.90	0.492	1.346
150	21.64	35.25	24.53	0.681	1.157
200	17.96	34.81	25.16	0.841	0.997
250	12.79	34.46	26.04	0.965	0.873
300	10.84	34.45	26.40	1.059	0.779
400	09.22	34.58	26.77	1.213	0.625
500	08.00	34.61	26.99	1.340	0.497
600	07.19	34.54	27.05	1.455	0.383
700	06.48	34.53	27.14	1.563	0.275
800	05.84	34.55	27.24	1.662	0.176
1000	04.73	34.59	27.40	1.838	0.000

STATION 21

M/V Hugh M. Smith: Cruise 26, 12°35'N, 165°45'W, June 8, 1954. Messenger time: 1555 GCT. Weather: 02, cloud coverage 7. Wind: 070°, 12 kt. Sea: 3-5 ft. Wire angle: 25°. Depth of water: 2300 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.11	34.60	22.41	4.70	
37	27.12	34.52	22.34	4.74	
75	27.12	34.65	22.44	4.68	
122	23.38	35.08	23.91	4.85	
169	15.79	34.54	25.46	3.62	
225	11.36	34.65	26.46	0.54	
286	10.56	34.69	26.63	0.29	
387	09.46	34.69	26.82	0.44	
482	08.76	34.65	26.90	0.55	
582	07.91	34.61	27.00	0.72	
582	07.86	-	27.01	-	
779	06.50	34.60	27.19	0.81	
976	05.28	34.63	27.37	1.11	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.11	34.60	22.41	0.000	1.791
10	27.11	34.68	22.39	0.054	1.736
20	27.11	34.58	22.38	0.109	1.682
30	27.12	34.54	23.36	0.164	1.627
50	27.12	34.62	22.42	0.274	1.517
75	27.12	34.65	22.44	0.410	1.381
100	24.93	34.99	23.38	0.535	1.256
150	18.52	34.65	24.89	0.728	1.063
200	12.00	34.62	26.31	0.850	0.941
250	11.02	34.67	26.54	0.934	0.857
300	10.22	34.69	26.69	1.009	0.782
400	09.39	34.68	26.82	1.147	0.644
500	08.59	34.64	26.92	1.275	0.516
600	07.74	34.60	27.02	1.395	0.396
700	07.05	34.60	27.12	1.507	0.284
800	06.32	34.60	27.22	1.610	0.181
1000	05.20	34.63	27.38	1.791	0.000

STATION 23

M/V Hugh M. Smith: Cruise 26, 11°11'N, 167°26'W, June 9, 1954. Messenger time: first cast 1615 GCT, second cast 1655 GCT. Weather: 02, cloud coverage 3. Wind: 090°, 20 kt. Sea: 5-8 ft. Wire angle: first cast 34°, second cast 27°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.27	34.42	22.22	4.71	
32	27.26	34.42	22.22	4.69	
68	27.27	34.51	22.29	4.67	
113	24.72	34.58	23.13	4.44	
163	12.32	34.52	26.17	1.10	
235	10.65	34.72	26.64	0.46	
299	09.75	34.70	26.78	0.53	
506	08.37	34.61	26.93	0.72	
610	07.41	34.58	27.05	0.50	
610	07.46	-	27.04	-	
822	05.88	34.58	27.26	0.62	
865	-	-	-	-	
1021	04.92	34.56	27.36	0.40	
1048	-	-	-	-	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.27	34.42	22.22	0.000	1.769
10	27.27	34.42	22.22	0.056	1.713
20	27.26	34.42	22.22	0.112	1.657
30	27.26	34.42	22.22	0.169	1.600
50	27.27	34.46	22.25	0.281	1.488
75	27.10	34.54	22.36	0.420	1.349
100	26.08	34.57	22.71	0.555	1.214
150	15.45	34.43	25.45	0.750	1.019
200	11.33	34.67	26.48	0.855	0.914
250	10.41	34.72	26.68	0.931	0.838
300	09.74	34.70	26.78	1.000	0.769
400	09.08	34.65	26.85	1.132	0.637
500	08.44	34.61	26.92	1.259	0.510
600	07.51	34.58	27.04	1.378	0.391
700	06.78	34.58	27.14	1.488	0.281
800	06.05	34.57	27.23	1.588	0.181
1000	04.95	34.57	27.36	1.769	0.000

STATION 25

M/V Hugh M. Smith: Cruise 26, 13°00'N, 168°13'W, June 10, 1954. Messenger time: 1548 GCT. Weather: 02, cloud coverage 3. Wind: 070°, 18 kt. Sea: 8-12 ft. Wire angle: 32°. Depth of water: 2900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.14	34.58	22.38	4.62	
46	27.14	34.58	22.38	4.67	
93	24.28	34.70	23.35	4.71	
140	19.84	34.76	24.64	4.47	
186	14.78	34.47	25.63	3.02	
233	12.20	34.45	26.14	1.85	
281	10.72	34.61	26.54	0.74	
379	09.64	34.63	26.74	0.42	
472	08.78	34.63	26.88	0.52	
565	07.70	34.58	27.01	0.51	
565	07.65	-	27.02	-	
747	06.31	34.52	27.16	0.77	
931	05.10	34.54	27.32	0.88	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	27.14	34.58	22.38	0.000	1.839
10	27.14	34.58	22.38	0.055	1.784
20	27.14	34.58	22.38	0.109	1.730
30	27.14	34.58	22.38	0.164	1.675
50	27.14	34.58	22.38	0.274	1.565
75	26.50	34.61	22.60	0.409	1.430
100	23.80	34.71	23.50	0.543	1.296
150	18.63	34.71	24.91	0.732	1.107
200	13.81	34.44	25.81	0.866	0.973
250	11.58	34.52	26.31	0.967	0.872
300	10.47	34.62	26.59	1.050	0.789
400	09.45	34.63	26.77	1.195	0.644
500	08.44	34.62	26.93	1.326	0.514
600	07.35	34.57	27.05	1.444	0.396
700	06.61	34.53	27.12	1.553	0.286
800	05.92	34.52	27.20	1.655	0.184
1000	04.87	34.54	27.35	1.839	0.000

STATION 25A

M/V Hugh M. Smith: Cruise 26, 14°33'N, 168°25'W, June 11, 1954. Messenger time: 0427 GCT. Weather: 02, cloud coverage 2. Wind: 070°, 15 kt. Sea: 5-8 ft. Wire angle: 22°. Depth of water: 900 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.70	34.69	22.60	4.54	
28	26.52	34.72	22.68	4.55	
61	25.84	34.79	22.94	4.63	
103	24.74	35.03	23.46	4.78	
146	23.94	35.23	23.85	4.62	
207	18.94	34.83	24.92	3.91	
312	10.89	34.43	26.37	1.51	
423	08.58	34.47	26.79	0.74	
530	07.38	34.47	26.97	0.68	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.70	34.69	22.60	0.000	
10	26.65	34.70	22.63	0.052	
20	26.56	34.71	22.66	0.105	
30	26.47	34.73	22.71	0.156	
50	26.03	34.77	22.87	0.258	
75	25.41	34.87	23.14	0.381	
100	24.80	35.01	23.43	0.497	
150	23.92	35.23	23.86	0.713	
200	19.64	34.89	24.79	0.898	
250	15.00	34.61	25.69	1.039	
300	11.61	34.45	26.25	1.145	
400	08.93	34.46	26.73	1.309	
500	07.66	34.47	26.93	1.440	

STATION 27

M/V Hugh M. Smith: Cruise 26, 16°01'N, 168°36'W, June 11, 1954. Messenger time: 1614 GCT. Weather: 02, cloud coverage 3. Wind: 070°, 15 kt. Sea: 8-12 ft. Wire angle: 14°. Depth of water: 1200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.54	34.43	22.46	4.80	
46	26.56	34.45	22.47	4.71	
87	25.38	34.87	23.15	4.84	
144	23.70	35.17	23.88	4.63	
200	19.11	34.88	24.92	4.18	
272	14.30	34.47	25.73	3.60	
338	10.65	34.27	26.29	2.96	
458	07.48	34.27	26.80	1.21	
571	06.52	34.27	26.93	0.97	
684	05.72	34.45	27.18	1.19	
904	04.80	34.65	27.44	1.03	
1126	03.96	-	-	1.27	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.54	34.43	22.46	0.000	
10	26.54	34.43	22.46	0.054	
20	26.55	34.44	22.46	0.108	
30	26.55	34.44	22.46	0.162	
50	26.50	34.48	22.51	0.270	
75	25.73	34.75	22.95	0.399	
100	24.91	34.98	23.37	0.518	
150	23.48	35.17	23.94	0.733	
200	19.11	34.88	24.92	0.913	
250	15.63	34.58	25.53	1.055	
300	12.70	34.36	25.98	1.172	
400	08.49	34.27	26.64	1.352	
500	07.10	34.27	26.85	1.491	
600	06.27	34.32	27.00	1.613	
700	05.63	34.47	27.20	1.719	
800	05.20	34.56	27.32	1.811	
1000	04.41	-	-	-	

STATION 29

M/V Hugh M. Smith: Cruise 26, 17°55'N, 169°37'W, June 12, 1954. Messenger time: 1605 GCT. Weather: 02, cloud coverage 3. Wind: 080°, 16 kt. Sea: 5-8 ft. Wire angle: 14°. Depth of water: 2700 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.13	34.79	22.86	4.75	
47	25.18	35.12	23.40	4.89	
88	24.40	35.30	23.77	4.92	
145	22.49	35.35	24.37	4.59	
202	19.84	35.21	24.98	4.50	
260	16.10	34.69	25.51	4.23	
343	10.96	34.27	26.24	3.31	
462	08.10	34.23	26.67	2.25	
575	06.32	34.33	27.00	1.23	
688	05.68	34.49	27.21	1.21	
909	04.75	34.54	27.36	1.15	
1128	03.98	34.58	27.48	1.21	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	26.13	34.79	22.86	0.000	1.915
10	26.13	34.79	22.86	0.050	1.865
20	26.13	34.79	22.86	0.100	1.815
30	26.13	34.79	22.86	0.150	1.765
50	25.01	35.16	23.48	02.45	1.670
75	24.59	35.27	23.69	0.354	1.562
100	24.21	35.32	23.84	0.458	1.457
150	22.23	35.35	24.44	0.651	1.264
200	19.89	35.21	24.97	0.818	1.098
250	16.78	34.78	25.42	0.961	0.954
300	13.40	34.41	25.87	1.084	0.832
400	09.45	34.22	26.45	1.279	0.637
500	07.42	34.24	26.78	1.430	0.485
600	06.12	34.38	27.07	1.553	0.363
700	05.64	34.49	27.22	1.655	0.260
800	05.21	34.52	27.29	1.748	0.168
1000	04.45	34.56	27.41	1.915	0.000

STATION 29A

M/V Hugh M. Smith: Cruise 26, 19°37'N, 169°50'W, June 13, 1954. Messenger time: 0438 GCT. Weather: 02, cloud coverage 2. Wind: 060°, 14 kt. Sea: 3-5 ft. Wire angle: 11°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.23	34.85	22.87	4.45	
15	26.20	34.90	22.92	4.28	
41	25.46	35.17	23.35	4.61	
89	24.49	35.19	23.66	4.72	
144	22.54	35.41	24.39	4.52	
196	20.33	35.23	24.87	4.19	
313	12.88	34.42	25.99	4.04	
419	08.95	34.23	26.54	3.36	
521	06.48	34.56	27.16	2.76	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.23	34.85	22.87	0.000	
10	26.21	34.89	22.91	0.050	
20	26.19	34.92	22.93	0.099	
30	25.53	35.16	23.32	0.147	
50	25.30	35.18	23.41	0.238	
75	24.90	35.18	23.53	0.349	
100	24.13	35.21	23.78	0.457	
150	22.35	35.41	24.45	0.650	
200	20.13	35.20	24.90	0.818	
250	16.91	34.81	25.41	0.963	
300	13.66	34.48	25.87	1.086	
400	09.54	34.23	26.45	1.281	
500	06.92	34.46	27.03	1.422	

STATION 31

M/V Hugh M. Smith: Cruise 26, 19°59'N, 169°12'W, June 13, 1954. Messenger time: 1615 GCT. Weather: 02, cloud coverage 2. Wind: 090°, 3 kt. Sea: 3-5 ft. Wire angle: 02°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.90	35.01	23.09	4.74	
27	25.81	35.10	23.19	4.77	
64	24.54	35.44	23.83	4.93	
118	22.67	35.32	24.29	4.96	
181	20.70	35.43	24.92	4.56	
252	16.46	34.67	25.41	4.51	
327	13.06	34.54	26.04	4.39	
439	09.10	-	-	3.79	
545	06.66	-	-	1.22	
656	05.76	34.29	27.04	1.24	
871	04.67	34.45	27.30	1.16	
1076	04.06	34.58	27.47	1.40	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.90	35.01	23.09	0.000	1.910
10	25.87	35.04	23.12	0.048	1.862
20	25.85	35.08	23.16	0.095	1.814
30	25.80	35.12	23.21	0.142	1.767
50	24.72	35.42	23.76	0.231	1.679
75	24.28	35.43	23.90	0.334	1.576
100	23.41	35.36	24.11	0.432	1.477
150	21.79	35.36	24.57	0.615	1.294
200	19.52	35.23	25.08	0.776	1.134
250	16.56	34.68	25.39	0.917	0.992
300	14.22	34.58	25.84	1.040	0.870
400	10.38	34.32	26.37	1.239	0.671
500	07.52	34.22	26.75	1.396	0.514
600	06.11	34.26	26.98	1.524	0.385
700	05.49	34.32	27.10	1.636	0.273
800	04.99	34.40	27.23	1.737	0.173
1000	04.26	34.54	27.41	1.910	0.000

STATION 33

M/V Hugh M. Smith: Cruise 26, 21°05'N, 168°16'W, June 14, 1954. Messenger time: 1605 GCT. Weather: 02, cloud coverage 2. Wind: 090°, 4 kt. Sea: 3-5 ft. Wire angle: 17°. Depth of water: 2400 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.31	35.17	23.40	4.55	
24	25.24	35.23	23.46	4.64	
49	24.56	35.26	23.69	4.45	
97	22.96	35.30	24.19	4.71	
146	21.27	35.35	24.70	4.52	
199	19.76	35.21	25.01	4.52	
298	14.36	34.45	25.71	4.23	
401	10.24	34.27	26.36	2.95	
499	07.90	34.25	26.72	1.71	
602	06.38	34.29	26.96	1.26	
804	05.10	34.40	27.21	1.00	
1004	04.48	34.54	27.39	1.14	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.31	35.17	23.39	0.000	1.915
10	25.29	35.19	23.42	0.045	1.870
20	25.26	35.22	23.45	0.090	1.826
30	25.09	35.25	23.52	0.134	1.781
50	24.54	35.26	23.70	0.220	1.695
75	23.80	35.28	23.93	0.323	1.592
100	22.63	35.31	24.30	0.419	1.496
150	21.18	35.35	24.73	0.594	1.321
200	19.75	35.20	25.00	0.753	1.162
250	17.13	34.78	25.33	0.898	1.018
300	14.22	34.44	25.73	1.025	0.890
400	10.30	34.27	26.35	1.233	0.682
500	07.88	34.25	26.72	1.393	0.522
600	06.40	34.29	26.96	1.524	0.392
700	05.60	34.34	27.10	1.636	0.279
800	05.11	34.40	27.21	1.738	0.177
1000	04.47	34.54	27.39	1.915	0.000

STATION 35

M/V Hugh M. Smith: Cruise 26, 20°51'N, 166°48'W, June 15, 1954. Messenger time: 1608 GCT. Weather: 15, cloud coverage 5. Wind: 060°, 8 kt. Sea: 5-8 ft. Wire angle: 16°. Depth of water: 2200 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.81	35.10	23.19	4.74	
25	25.80	35.10	23.19	4.77	
51	24.54	35.16	23.62	4.99	
101	22.40	35.25	24.31	4.88	
152	19.70	35.03	24.88	4.31	
207	16.94	34.72	25.33	4.26	
308	11.19	34.20	26.14	3.92	
414	08.06	34.13	26.60	3.15	
515	06.32	34.14	26.85	1.66	
621	05.44	34.25	27.05	1.08	
828	04.69	34.42	27.27	1.06	
1029	04.16	34.52	27.41	1.27	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.81	35.10	23.19	0.000	1.810
10	25.81	35.10	23.19	0.047	1.764
20	25.80	35.10	23.19	0.094	1.717
30	25.79	35.10	23.20	0.141	1.670
50	24.59	35.15	23.60	0.231	1.579
75	23.60	35.21	23.94	0.335	1.475
100	22.46	35.24	24.29	0.432	1.379
150	19.89	35.05	24.85	0.604	1.207
200	17.27	34.76	25.28	0.752	1.058
250	14.44	34.45	25.69	0.882	0.929
300	11.55	34.22	26.09	0.992	0.819
400	08.44	34.13	26.54	1.171	0.639
500	06.50	34.14	26.83	1.316	0.495
600	05.58	34.23	27.02	1.437	0.373
700	05.09	34.34	27.16	1.544	0.267
800	04.72	34.41	27.26	1.639	0.171
1000	04.22	34.50	27.39	1.810	0.000

STATION 37

M/V Hugh M. Smith: Cruise 26, 21°14'N, 164°11'W, June 16, 1954. Messenger time: 1600 GCT. Weather: 02, cloud coverage 3. Wind: 060°, 2 kt. Sea: 3-5 ft. Wire angle: 00°. Depth of water 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.04	34.65	22.78	4.52	
27	25.70	34.78	22.98	4.63	
49	25.16	34.92	23.25	4.70	
106	23.42	35.26	24.03	4.59	
159	21.29	35.17	24.56	4.42	
218	18.36	34.92	25.14	4.05	
324	11.72	34.25	26.08	3.95	
435	07.86	34.13	26.63	2.87	
541	06.41	34.14	26.84	1.64	
652	05.62	34.25	27.03	1.01	
866	04.74	34.45	27.29	1.13	
1072	04.14	34.54	27.43	1.16	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.04	34.65	22.78	0.000	1.942
10	26.02	34.67	22.80	0.051	1.892
20	25.92	34.70	22.86	0.101	1.841
30	25.61	34.81	23.03	0.151	1.792
50	25.15	34.93	23.26	0.246	1.697
75	24.51	35.07	23.56	0.358	1.584
100	23.65	35.23	23.94	0.463	1.479
150	21.70	35.20	24.47	0.653	1.290
200	19.40	35.02	24.95	0.819	1.124
250	16.35	34.69	25.45	0.962	0.981
300	13.11	34.34	25.88	1.083	0.860
400	08.71	34.14	26.51	1.275	0.668
500	06.90	34.13	26.77	1.424	0.519
600	05.95	34.20	26.95	1.552	0.390
700	05.40	34.30	27.09	1.666	0.277
800	04.94	34.39	27.22	1.766	0.176
1000	04.32	34.51	27.38	1.942	0.000

STATION 39

M/V Hugh M. Smith: Cruise 26, 20°51'N, 161°59'W, June 17, 1954. Messenger time: 1607 GCT. Weather: 02, cloud coverage 2. Wind: calm. Sea: 3-5 ft. Wire angle: 07°. Depth of water: 2600 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.89	34.81	22.95	4.63	
26	25.68	34.81	23.01	4.78	
52	25.07	34.87	23.24	4.90	
104	23.86	35.19	23.85	4.82	
157	22.67	35.30	24.28	4.81	
215	19.68	35.07	24.92	4.26	
319	13.03	34.27	25.84	3.89	
429	08.88	34.16	26.50	2.90	
533	06.82	34.13	26.78	1.72	
642	05.87	34.25	27.00	1.07	
854	04.88	34.42	27.25	0.99	
1058	04.22	34.51	27.40	1.12	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.89	34.81	22.94	0.000	2.026
10	25.88	34.81	22.95	0.049	1.976
20	25.79	34.81	22.97	0.098	1.927
30	25.61	34.81	23.03	0.147	1.878
50	25.18	34.86	23.20	0.243	1.783
75	24.60	34.98	23.47	0.357	1.668
100	23.99	35.16	23.78	0.465	1.560
150	22.79	35.30	24.24	0.664	1.362
200	20.39	35.14	24.78	0.840	1.186
250	17.45	34.81	25.28	0.991	1.035
300	14.24	34.41	25.70	1.121	0.905
400	09.83	34.17	26.35	1.329	0.696
500	07.38	34.13	26.70	1.490	0.536
600	06.20	34.19	26.91	1.624	0.402
700	05.55	34.30	27.08	1.740	0.286
800	05.08	34.38	27.20	1.843	0.182
1000	04.41	34.48	27.35	2.026	0.000

STATION 41

M/V Hugh M. Smith: Cruise 26, 21°17'N, 160°01'W, June 18, 1954. Messenger time: 1628 GCT. Weather: 02, cloud coverage 4. Wind: 080°, 10 kt. Sea: 5-8 ft. Wire angle: 27°. Depth of water: 2500 f.

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.60	34.88	23.09	4.77	
22	24.12	35.14	23.73	5.03	
45	23.00	35.26	24.15	5.10	
89	21.96	35.26	24.44	4.89	
134	20.92	35.28	24.75	4.78	
183	19.08	34.99	25.01	4.43	
273	13.77	34.36	25.76	3.91	
366	10.22	34.16	26.28	3.40	
456	08.20	34.18	26.62	2.14	
549	06.66	34.22	26.87	1.30	
733	05.02	34.38	27.21	0.72	
912	04.37	34.49	27.36	0.93	

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t	ΔD (dyn. m)	$\Delta D\,1000 - \Delta D$ (dyn. m)
00	25.60	34.88	23.09	0.000	
10	25.60	34.88	23.09	0.048	
20	24.22	35.13	23.70	0.093	
30	23.70	35.20	23.90	0.134	
50	22.84	35.27	24.20	0.212	
75	22.25	35.26	24.36	0.304	
100	21.62	35.27	24.55	0.392	
150	20.39	35.23	24.85	0.558	
200	18.10	34.85	25.15	0.710	
250	14.73	34.45	25.62	0.843	
300	12.65	34.27	25.92	0.959	
400	09.38	34.16	26.42	1.154	
500	07.43	34.20	26.75	1.309	
600	06.08	34.26	26.98	1.437	
700	05.26	34.35	27.15	1.546	
800	04.72	34.42	27.27	1.642	

CONSIDERATION OF MIDOCEAN FISH PRODUCTION RELATED TO OCEANIC CIRCULATORY SYSTEMS

By

OSCAR E. SETTE

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U. S. Fish and Wildlife Service

The sea receives most of the radiant energy reaching the ea simply because there is more sea than land, especially in middle low latitudes where the angle of incidence is greatest and the loss reflection is least. Therefore, so far as total absorption of energ concerned, the sea's productive capacity should greatly exceed t of the land. Indeed Riley (1944) has estimated carbon produc in the sea to be about 86% of the total carbon production on the ea both land and sea combined. Steemann-Nielsen (1952), by a diffe method of measuring carbon fixation in sea water, arrived at a m lower rate of production, but even this lower rate would leave production capacity of the sea equal to that of the land.

By contrast, man's total harvest of organic material from sea is at least a whole order of magnitude lower than that from land. Practically all of this harvest is taken from the margins of sea. The oceanic part, beyond a depth of 1,000 m, comprises ne 90% of the sea area, and from this major portion man's present har is trivial.

It is proposed in this essay to examine the means by which m may extract some of the organic wealth from this major pelagic fract of the sea. Illustrative material will be drawn from what I beli to be the first attempt to focus scientific effort of nearly adequ scale directly on this problem. For this reason, it will be conveni to use a narrative arrangement, and consideration will be limited the oceanic middle and low latitudes of the Pacific Ocean and to extraction of organic materials in the form of edible fish.

The scientific effort to which I refer is the activity of the Pac Oceanic Fishery Investigations of the U. S. Fish and Wildlife Serv headquartered at Honolulu, Hawaii, and assigned to the task investigating the high-seas fishery potential of the tropical and s tropical mid-Pacific waters. Three vessels, the Hugh M. Smi the John R. Manning, and the Henry O'Malley, later repla

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e CHARLES H. GILBERT, have now been operating on this program
½ years. The first-named has performed most of the oceano-
ic work while the other two have been engaged primarily in
ng the fish stocks through systematic fishing surveys.
waii is located near the middle of the sluggish westward-moving
h Equatorial Current. In this Current a warm upper layer
es the colder water and forms a two-layer system of persistent
ity. Typically, the warm surface layer is at least 100 m thick
as a phosphate concentration of 0.2 to 0.4 μg-at/l; zooplankton
rse, averaging 20 ml displacement volume per 1,000 m³ in the
200 m layer as sampled with a 0.65 mm meshed net. Such
s are obviously an unpromising environment for supporting
fish stocks unless there exist situations where the vertical sta-
l of the two-layer system is modified so that the underlying
nt-rich water is mixed into the lighted upper layer in greater
rtion than is prevalent in the North Equatorial Current.
was our hypothesis that in situations of such modified vertical
ty there would be chemical enrichment of the euphotic zone,
irting increased biological productivity and large stocks of fish,
is is true wherever there are mechanisms for enrichment in the
nal seas flanking the continents.
ee such situations have received varying degrees of attention
the last four years: the equatorial divergence-convergence
a south of Hawaii; the boundary between the North Equatorial
nt and the North Pacific Drift north of Hawaii; and the pertur-
s within the North Equatorial Current as it flows past or through
Hawaiian Islands group. Each of these involves a different
al mechanism for energy transformation into vertical motion:
ling in the first situation; current interface shearing in the second;
ddies and wakes in the third. All of these situations appear
ve for producing important concentrations of fish. Our knowl-
egarding the first is now considerable. It is only fragmentary
e second and third. Even in the first situation there remain
areas of ignorance in our understanding of the physical and
ical phenomena involved.
the outset of our investigation, upwelling along the Equator,
orded in the data of the CARNEGIE expedition of 1928–1929
s interpreted by Sverdrup, *et al.* (1942; 710), appeared to be
ost promising large-scale mechanism for producing concentra-
of fish. Here, some kinds of fish should be abundant if our
hesis was valid. It was hoped that these would include the
ropical and subtropical species of tuna that are of greatest
ercial importance, namely the yellowfin tuna, *Neothunnus*

macropterus Temminck and Schlegel, and the skipjack, *Katsuwo pelamis* Linnaeus.

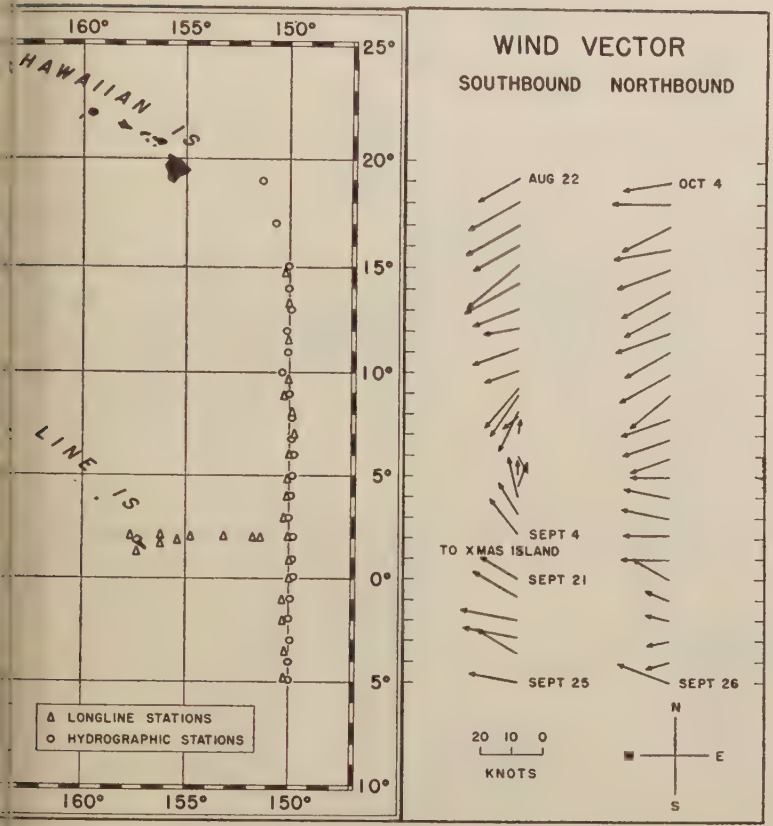
Accordingly we undertook an intensive study of the equato current system. It has now been under way for four years. In t period we have made 16 hydrographic traverses of the current syst at various meridians from Long. 140° to 180° W. On all of th traverses, bathythermograph casts were added between statio usually at 10-mile intervals, and about 30 additional BT sections w made on fishing voyages. These extend our knowledge of the detai temperature field down to 900 feet as far east as Long. 110° W. Seve of the hydrographic traverses extended to Lat. 24° N and one to 14 However, the rectangle between Long. 140° and 180° W and I 12° N and 10° S has been the most thoroughly explored. On ma of the traverses, zooplankton hauls were made with a conventio meter-net, hauled obliquely from the surface to 200 m, with the f through the net measured by a current meter.

These observations proved that there was indeed an upward mo ment of water at the Equator (Cromwell, 1951) and that it w accompanied by a greater concentration of zooplankton (King a Demond, 1953) in the vicinity of the Equator than in adjacent hig latitudes.

Despite the consistent evidence of chemical enrichment acc panied by zooplankton abundance, extensive fishing trials made the three principal methods used in the California commercial tu fishery (live-bait chumming, purse-seining, and trolling) pro disappointing. Except for small areas in the immediate vicin of the few low-latitude islands in the region, tuna were not cau in the zonal band of enrichment.

Faced with this contradiction, we employed a fourth fishing meth heretofore used only by the Japanese. Known as the "longlin this consists of a mainline suspended from surface buoys at interv and provided with baited hooks hung by dropper lines at interv along the mainline. This gear is constructed in units, known "baskets," which are joined end to end and which may extend ma miles. In our survey fishing, 12 miles of line are set, with the bu line lengths and the slack in the mainline so adjusted that hooks fish at various levels from 100 to 400 feet, or for all practi purposes, throughout the entire warm layer and down partly into transition layer.

This method of fishing proved to be satisfactory for sampling larger pelagic carnivores and gave results consistent with the ocea graphic findings. It has now been employed to delineate the tribution of tunas over a rectangle of about 4,000,000 square m



. 1. Hydrographic and fishing stations occupied by the HUGH M. SMITH from 22 to September 26, 1951 (left) and the average direction and force of the wind at along her track (right).

Lat. 10° N to 5° S and from Long. 110° to 180° W. Further, iciency of this gear, first thought to be too low for use in the an economic structure, has proved sufficiently high to support an commercial operations when such gear is used in the areas greatest concentration of tuna as delineated by our surveys. findings with this sampling instrument in relation to the equa- current system may be illustrated by an example along Long. V. During her Cruise 11 in August and September 1951, the M. SMITH combined hydrographic, plankton, and longline ions along the track shown in Fig. 1. On the southbound se the winds were nearly typical for the region: northeast trade

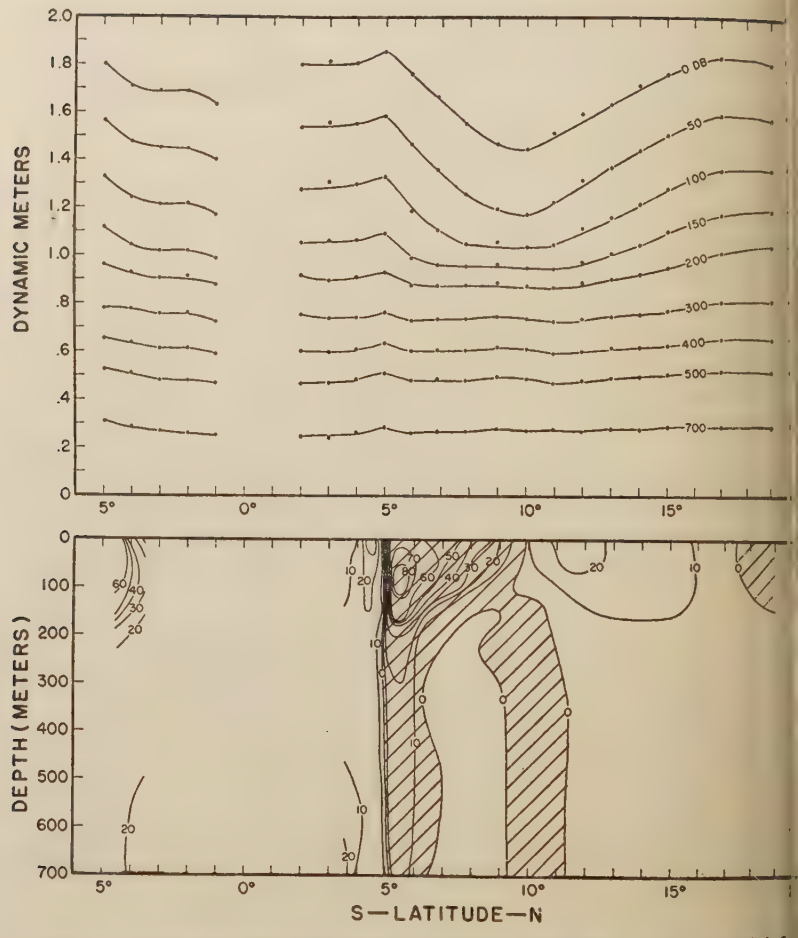
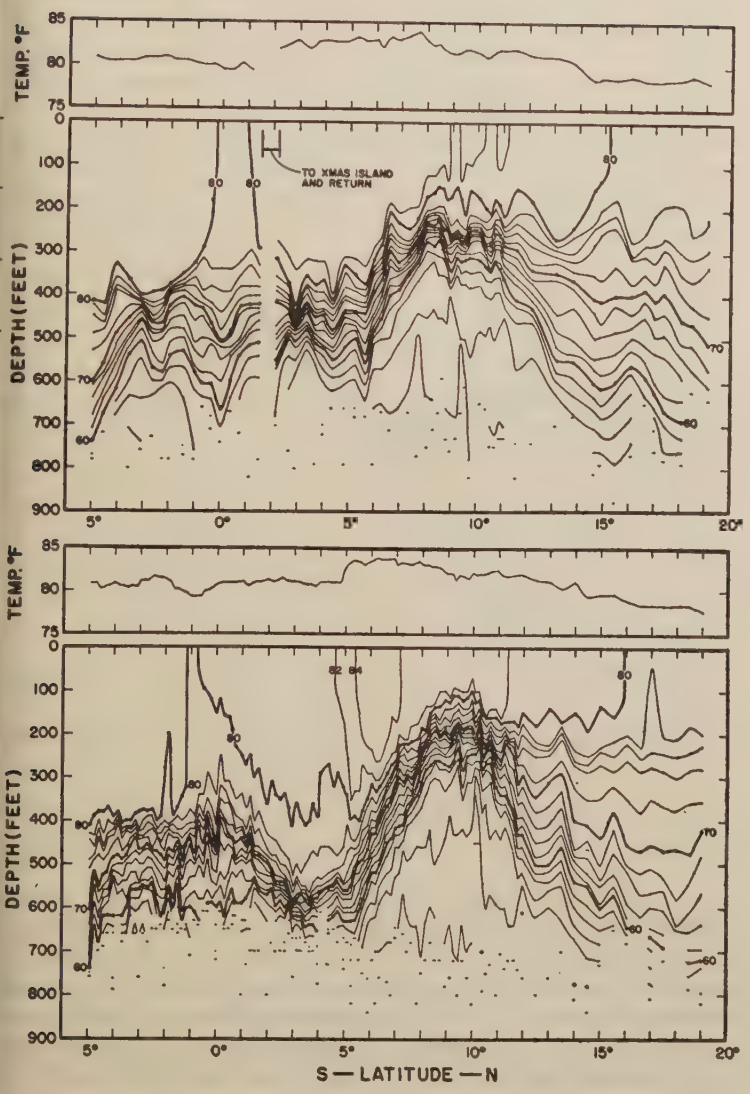


Figure 2. Dynamic topography (upper) and field of horizontal velocity (lower) infe from geostrophic analysis of hydrographic data taken along the 150th W meridian by Hugh M. Smith, August 22 to September 25, 1951. The unshaded portion repres flow to the west, the shaded portion flow to the east.

winds in the northerly portion of the traverse, southeast trade wi in the southerly portion, with light and variable winds betw Lat. 5° and 9° N in a doldrum belt that separates the two trade w systems. On the northbound traverse a month later, the doldr belt was not in evidence, easterlies prevailed in the south, and transition to northeast trade winds at 5° N was immediate. G strophic analysis (Fig. 2) of data from the northbound trav



3. Vertical fields of temperature as measured by bathythermograph on traverses e 150th W meridian: August 22 to September 25, 1951, southbound (upper) and er 26 to October 4, 1951, northbound (lower).

places the Countercurrent in its usual position between Lat. 5° 9° N with a strong eastward flow of 80 cm/sec at its core. The d of longline (Fig. 7) confirms this interpretation and also betrays strong easterly undercurrent at the Equator, recently described Cromwell, *et al.* (1954).

The transverse circulation is suggested by the distribution properties in cross-section. Temperature (Fig. 3), density (Fig. and inorganic phosphate (Fig. 5) show a weakening of stability at Equator. The isopleths for 80°F, for σ_t23.0, for 0.6 μg-at PO_4

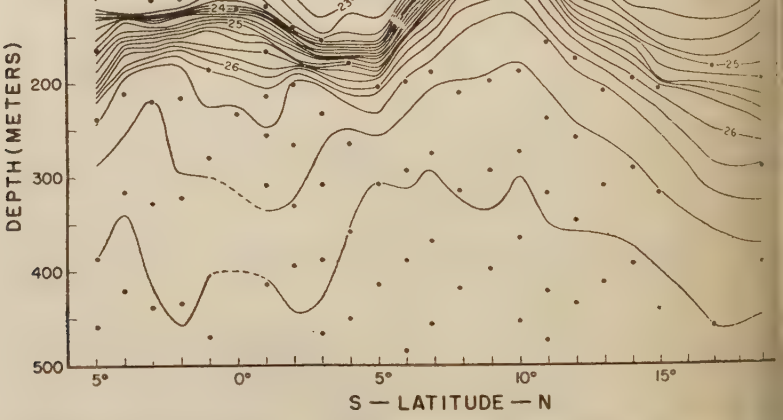
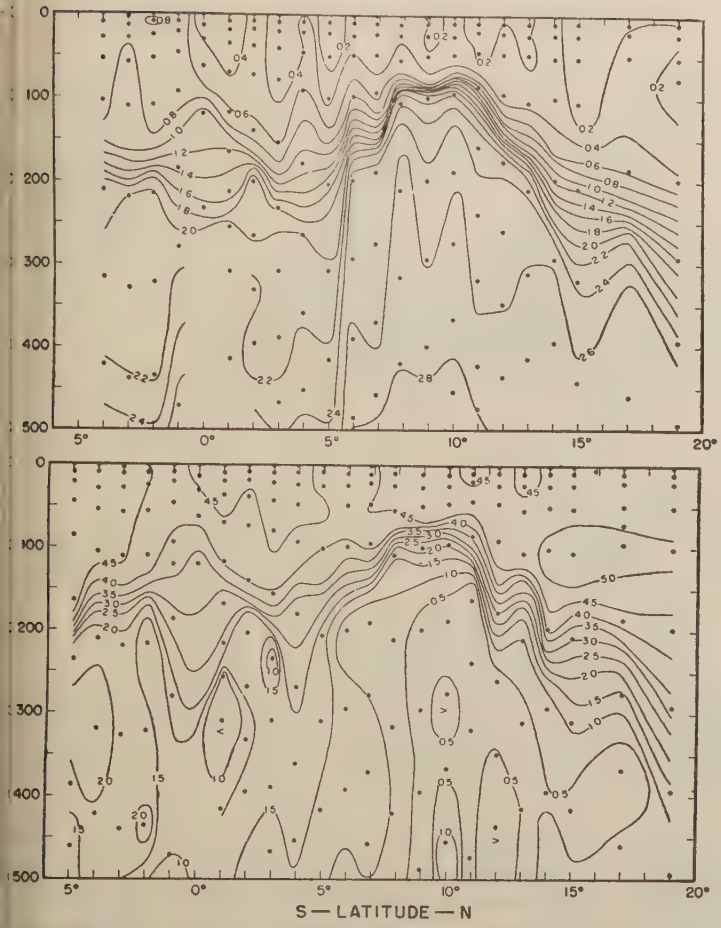


Figure 4. Vertical field of density along 150th W meridian, September 26 to Octob 1951.

and for 4.5 ml O_2/l ascend nearly vertically to the surface at near the Equator, indicating relatively freer vertical exchange thro the upper part of the water column at the Equator than elsewh along the traverse. The isopleths immediately below those m tioned bend upward. This suggests that the exchange involve least part of the underlying transition layer. In the deeper la they dip downward under the Equator. Whether this is indica of still deeper exchange is problematical.

It is not my intention here to elucidate fully the dynamics of transverse equatorial circulation. As already suggested, there features of it which are only partially understood and others are understood at all. However, Cromwell (1953) has offered a mo



. 5. Inorganic phosphate in microgram atoms per liter (upper) and oxygen in s per liter (lower) along the 150th W meridian, September 26 to October 4, 1951.

on isentropic principles, which relates the transverse circulation winds and accounts for the major features we have observed distribution of properties in cross-section (Cromwell, 1954; , 1954). We have reproduced in Fig. 6 the diagram of the erse circulation as published by Cromwell (1953: Fig. 7). , the stress of easterly winds impels the surface water in a y direction at the Equator, but the Coriolis force north and of the Equator tends to deflect the surface water poleward rom the Equator, where deeper water rises toward the surface.

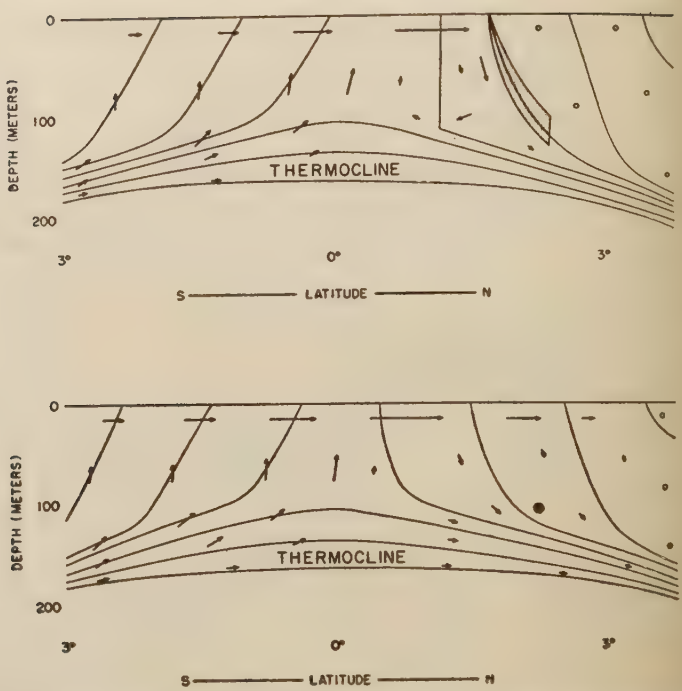
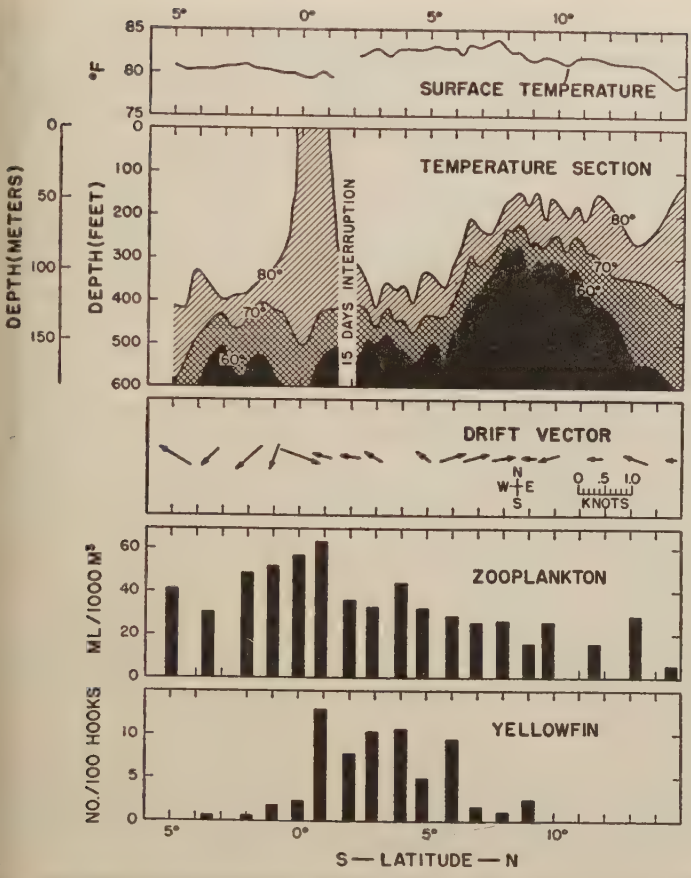


Figure 6. Schematic representation of circulation in the meridional plane near the Equ during a southeast wind when a front is present (upper) and when no front is present (low Lines represent surfaces of constant density. Arrows have the character of streamlines, trajectories, and their shafts indicate roughly the relative magnitudes of flow. A Cromwell (1953: fig. 7).

Asymmetry is introduced when there are northerly or southe components in the easterly wind. For instance, according to Cro well, southeast trade winds displace the center of the upwelling the south of the Equator. This appears to have been the condit during Cruise 11 of the HUGH M. SMITH.

North of the Equator the upwelled water probably sinks, form a zone of convergence between the center of the upwelling and southern edge of the Countercurrent. Fronts are sometimes pres in this convergence zone. The sinking water may return southw at deeper levels, thus completing a cell, or it may continue northwa diving under the Countercurrent. In the latter event, associa movement in other directions would be required by the principle continuity.

When the zooplankton and fish catches along Long. 150° W compared with the temperature section (Fig. 7), it is seen thai



re 7. Surface temperature, vertical temperature field, longline drift, zooplankton nce in the upper 200 m, and the yellowfin tuna catch along Long. 150° W, August 22 ember 25, 1951.

ton concentrations are high in the vicinity of the Equator and he tuna concentration is high in the zone of convergence. The cement of the tuna northward from the plankton maximum unexpected since at least one trophic level (small fishes, crus-, and squids) intervenes in the food chain.[1]

ıe upwelling seems to be absent at the northern boundary of the tercurrent, though the transition layer here ascends so near the

peculative discussion of this displacement and also of the lack of a comparable oncentration south of the Equator was given at the 8th Pacific Science Con- Sette, in press).

surface that a brief[2] invasion of the doldrum belt by high winds migi stir the deeper, cooler, richer waters into the surface layer.[3] This ev dently does not occur regularly enough to establish a trophic successic culminating with large fish, for we have not found a zone of yellowfi tuna concentration in or along the northern boundary of the Counte current, nor indeed in any part of the Countercurrent.

However, in the convergent zone area between the Equator and th Countercurrent, or sometimes in a band centering at the Equato we have never failed to find a zone of much better longline tu fishing than at adjacent higher latitudes. The quantities of cato and the positions of the zone in the north-south direction have varie considerably,[4] probably in response to accelerations and deceleratio as well as to the swaying north and south of the current syster Although our observations have not had sufficient continuity in tin and space to elucidate these variations, it remains quite clear that th divergence-convergence features of the transverse equatorial circul tion provide the basic support for a persistent concentrated stoc of yellowfin tuna.

The yellowfin tuna sampled by our survey are the older, larg individuals of the species, ranging from 60 to 180 lbs. and averagi about 100 lbs. The younger members of the species are near absent from our longline catches. So also are the skipjack. In o equatorial plankton hauls, however, the yellowfin tuna larvae occ regularly, and the skipjack larvae outnumber the yellowfin larv by about three to one (Fig. 8). Obviously, equatorial waters mu harbor young yellowfin in greater quantities than older ones (to allo for mortality), and in addition they must support still greater numbe of skipjack. A truly enormous oceanic fishery may be envisione when the full potentials of this area are realized.

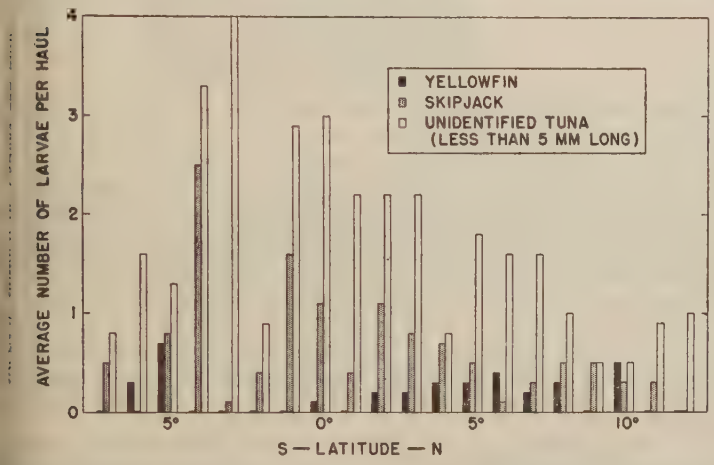
The east-west extent of the equatorial stock is limited only by th two continents, which at the Equator lie 10,000 miles apart. To b sure, this entire extent does not enjoy the high concentration we hav found south of Hawaii. This concentration seems to be the cons quence of the unequal stress of the easterly winds along the Equato According to Cromwell's model, the upwelling should occur alon

[2] The probably short-lived invasion by moderate northeast winds during th northbound traverse of the Hugh M. Smith apparently was without discernib effect on the vertical distribution of phosphate.

[3] This may have happened sometime prior to July 1952, for in that month u usually high plankton catches were taken in and immediately north of the Counte current along Long. 140° W. This is the only instance of such catches among th many zooplankton sections we have made across the Countercurrent.

[4] Some examples are given by Murphy and Shomura (1953).

intire extent of the Equator lying under easterly winds, but it 'd be strongest and the enrichment of surface waters should be .est where the winds are strongest and most sustained. Accord- o Pilot Charts, the average wind force is maximal at about Long. W. Therefore, the greatest enrichment should occur on the ge at about the 120th meridian. If the two phenomena, maxi- enrichment and maximal tuna concentration, are in cause and relationship to each other, then the westward flow of the water rrently with the passage of the biota through at least three



re 8. Average numbers of tuna larvae taken per oblique tow of 30 minutes duration h the upper 200 m layer with a one-meter tow-net having 0.65 mm mesh apertures. mples were collected along various longitudes from 140° to 180° W and in various during the period from June 1950 to July 1952. Larvae under 5 mm in length were ntified as to species.

ic levels (phytoplankton, zooplankton, and smaller nekton) d have rates in reasonable relation to the distance involved. rcel of water travelling westward from Long. 120° to 150° W at ate of ½ to 1 knot (an estimate based on drift of longline in the rgence zone just north of the Equator) would be carried 1,800 to the zone of best tuna fishing in about 75 to 150 days. Whether t this is a reasonable period of time for the three trophic levels velopment is a speculative question. It does not appear to ntastic, however, and it is the most cogent explanation I can offer e special concentration of tuna at Long. 150° to 170° W (Fig. 9). is concentration of tuna directly south of Hawaii is now under- development as a commercial tuna fishery resource by American men. The lesser concentrations of yellowfin tuna lying west

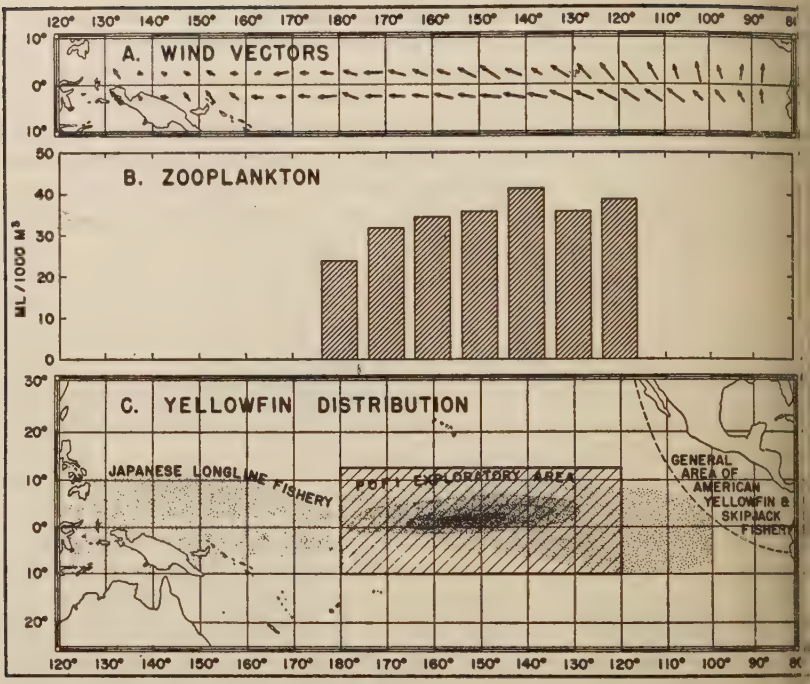
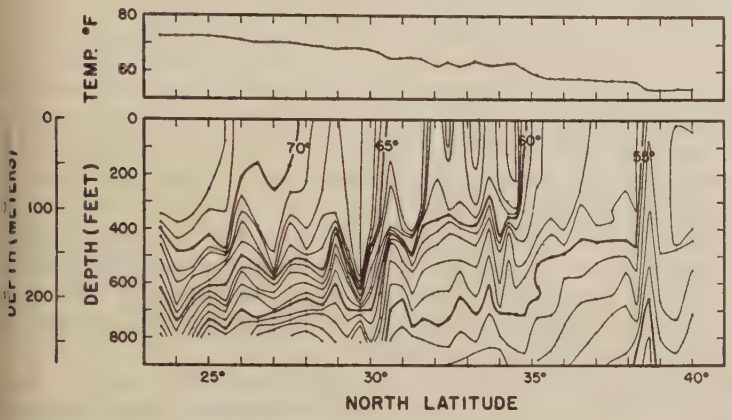


Figure 9. Wind, plankton, and tuna distribution in the equatorial zone. *A.* Resulta wind vectors were computed as the weighted means of frequency and speed from the sever compass points for 5-degree squares bordering the Equator as published in the U. S. Hydr graphic Office Pilot Chart for the North Pacific for August 1952; the arrows point in the dire tion of travel and their shafts are propertional to the weighted mean speed. *B.* Me plankton volumes at several longitudes were computed as the mean of all hauls taken b tween Lat. 5° S and 10° N at or near the given longitude. *C.* Distribution of yellowfin tu in the mid-Pacific equatorial region is estimated from longline catches. The light stippli in the POFI area represents less than three yellowfin tuna per hundred hooks, the heavie represents more than nine per hundred hooks, and the intermediate stippling represen intermediate catching rates. For orientation as to location and area, the extensive ba of light stippling represents the area of the Japanese prewar longline fishery; the dash outline shows the area of the American west coast live bait and purse seine fishery for yellowf and skipjack tuna. Since preparation of the above chart, a line of fishing stations alo Long. 110° W has proved the continuity of the band of yellowfin tuna across the "unexplor area."

of the 180th meridian are already commercially useable in the Jap nese economy. The lesser concentration to the east of Long. 150° W should ultimately be useable in the American economy when oceano graphic advances make the finding of local concentrations withi the convergence zone more sure and when technological advance make the fishing methods more efficient. It is perhaps not over

histic to say that a vast oceanic fishery resource is well on the toward full utilization.

is initial success of our hypothesis as a working tool for dis- ring fishery potentials in the oceanic two-layer system encouraged extend this type of approach in research to the second situation, hear zone between the North Equatorial Current and the North ic Drift. In this more northerly latitude a cool-water tuna, lbacore, *Germo alalunga* (Bonnaterre), may be expected. Indeed, apanese have already developed a fishery for this species in the rn Pacific between Lat. 30° and 40° N and between their home ls and the longitude of Midway Island some 2,500 miles eastward.



re 10. The vertical field of temperature as drawn from uncorrected bathythermo- along Long. 160° W in January 1954.

(1953) has attributed this fishery to a feature he designates as ubtropical Convergence.

r first reconnaissance north of Hawaii in January through March crossed the North Equatorial Current into the North Pacific along 10 meridional lines between Long. 140° and 165° W. The from these crossings are not yet processed.[5] A preliminary erature section (Fig. 10), drawn from uncorrected bathythermo- recordings, suggests a broad zone of complex thermal structure most pronounced transitional features at Lat. 34° N. In several nces the bunching of isotherms in their vertical ascent from the

e fishery research vessel N. B. SCOFIELD of the California Department of d Game, in cooperation with the Scripps Institution of Oceanooraphy, made ore meridional sections between 140° W. longitude and the American west

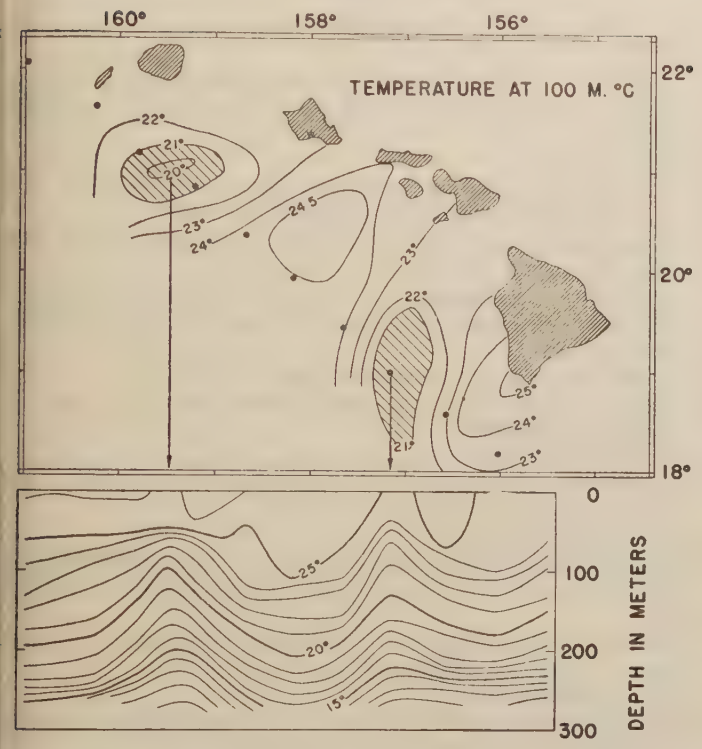
transition layer to the sea surface may result from eddy fragmentati in the shear zone. Their significance to vertical exchange must awa further study. Between Lat. 30° and 35° N the longline fishing ga evidence of abundant fish life, including bigeye tuna, *Parathunn sibi* Temminck and Schlegel, a species presently not considered good canning variety, sharks, lancet fish (*Alepisaurus* sp.), and misc laneous others including what is probably a new species of pela sting ray. At 34° on this section an outstanding catch of albaco was made. It seems quite likely, therefore, that we have here general locality where the second type of vertical circulation provid the potentials of a fishery.

The third mechanism, which concerns vertical circulation of deep waters into the euphotic zone within the North Equatorial Curre system, should occur where islands interrupt the current's flo This is suggested by the existence of a small but productive skipja fishery in Hawaii. After vainly searching for enriching mechanis connected with perturbations in the current flow past these islan we recognized last summer the presence of relatively large-scale a semipermanent eddies downstream from the Hawaiian Islan Curiously enough, these were recorded in the very first oceanograph observations taken by the Hugh M. Smith in the course of her shak down trip in December 1949. They were first recognized howev by GEK observations taken last summer. Both convergent a divergent types of eddies are formed (Fig. 11).

Near the boundary of one of the divergent eddies and far beyo the range of the present small local Hawaiian skipjack fishery, sy tematic scouting operations recorded many more skipjack scho than were sighted in the near-shore grounds or in neighboring offsh waters (Royce and Otsu, MS). This concentration was found two occasions. Both times it was near the western edge of the mo pronounced divergent eddy. This suggests that the eddy syste has within it a train of physical and biological events of significan to the support of the fish. Also, the finding of these concentratio well outside the range of the present fishery suggests further that t productivity of this middle portion of the North Equatorial Curre has potentials far beyond those suggested by the existing small loc fishery.

Thus it appears that there are three situations in oceanic wate where the two-layer system is sufficiently modified to permit t vertical exchange necessary for supporting commercial fish stock Others may become apparent as our knowledge increases.

In comparison with the fisheries of marginal seas, the utiliza of such oceanic fishery resources affords special opportunity



e 11. Temperature at the 100-m level (upper) and in a vertical section passing the black dots of the upper diagram (lower) southeast of the Hawaiian Archipelago st 1954.

ographic research to be of signal service. Unlike the fisheries rginal seas, which were developed essentially by following raphic features to their seaward limits, the development of c fisheries requires launching out beyond topographical land- literally into the deep blue. Success in locating fish resources deep blue does not reward the hit or miss method. Past res in the hands of so-called practical fishermen have proved r the oceanic Pacific. At least four such ventures, incurring ns of dollars of expenditure, took place during the five years ing the commencement of our work. None was successful. men's lore, evolved in the topographical setting of marginal s not effective for guidance in oceanic fishing. Oceanographic h, on the other hand, promises to be effective in providing the l guidance.

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An Invitation to Systematic Zoologists

ific Oceanic Fishery Investiga-
h headquarters in Honolulu is
a program of exploration, in-
, and development of the high
y resources of the central Pa-
undamental importance to our
rogram is the relative produc-
amount of basic fish food in
cean areas. Since the inaugura-
d work in 1949, our attempts to
quantitatively the abundance of
at the various eutrophic levels
led extensive collections of zoo-
fish, and miscellaneous inverte-

ve employed a variety of sam-
hods and types of gear; plankton
gic trawls, light traps, dip net-
nd a light, hand lining, and
otenone) have all been used.
achs of tunas, marlins, lancet
have been a rich source of or-
not collected by the usual meth-
le we have sampled a number of
ents—lagoons, coastal reefs, and
s adjoining the oceanic islands—
in the upper layers of the open
m the surface to a depth of sev-
dred meters has been most in-

Department of the Interior, Fish and
Service.

tensive and extensive. We have not explored the deeps nor dredged the bottom.

In those collections that lend themselves to quantitative analysis, the constituents have been sorted into major taxonomic groups, counted or the number estimated, and their displacement volumes determined. The counts and volume data have been used in comparing the standing crop of potential fish food in different ocean areas with particular hydrographic features of the environment and with the abundance of tunas as determined from our experimental fishing.

Although not primarily concerned with systematic zoology, we have made a diligent effort to identify the organisms as precisely as practical. Those forms that were prominent in our collections and considered important items of fish food were usually identified to species, frequently with the help of specialists at the University of Hawaii and the Bernice P. Bishop Museum. However, for many groups the taxonomy is not well organized and most of our material is only classified to genus or family, in the case of the fishes, and to family or order in the invertebrates.

Certain families of the fishes, special

(*Concluded on p. 42*)

An Invitation to Systematic Zoologists

(*Concluded from p. 40*)

groups of the invertebrates, and aliquots of zooplankton collections have already been made available to students and other research workers at the University of Hawaii and the Bernice P. Bishop Museum, and to specialists at several institutions on the mainland of the United States. The bulk of our collections, however, have not been thoroughly worked over. We now have on hand specimens representing about 95 fish families and practically all of the major invertebrate groups. We also have extensive zooplankton collections, unsorted except for removal of extra large organisms and tuna eggs and larvae. It is our desire that this material receive the fullest possible use, and we believe that thorough taxonomic treatment will uncover many forms new to science, make a significant contribution to our knowledge of Pacific fauna, and provide information needed in our research program.

Therefore, we invite the participation of taxonomic specialists. We will pack and ship any portion of our collections to a qualified investigator who can give the material his prompt attention and who will undertake to provide us with certain information we need. He may use the material to further his own studies in any way he chooses and may publish his findings as he pleases. In many instances the published paper, in the form of
will furnish the information we n
may ask, in addition, interim lists
cies, annotated as to collection
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While in the hands of the inve
the specimens will be in a loan
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The first set of identified specime
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be transferred by the United State
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National Museum. In many instanc
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quest the return of a set of ide
specimens for reference purpose
equitable distribution will be made
remaining duplicate series or sets of
mens.

We invite correspondence indi
the field of interest and requestin
terial.

O. E.
Pacific Oceanic Fishery Investigati
Honolulu, Hawaii

COMPARATIVE STUDY
F LONGLINE BAITS

SPECIAL SCIENTIFIC REPORT–FISHERIES No. 151

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Explanatory Note

The series embodies results of investigations, usually of restr
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as guides for administrative or legislative action. It is issued in li
quantities for the official use of Federal, State or cooperating Agen
and in processed form for economy and to avoid delay in publicatio

United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

A COMPARATIVE STUDY OF LONGLINE BAITS

By

Richard S. Shomura
Fishery Research Biologist
Pacific Oceanic Fishery Investigations
Honolulu, T. H.

Special Scientific Report: Fisheries No. 151

WASHINGTON: JUNE 1955

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A COMPARATIVE STUDY OF LONGLINE BAITS

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The Pacific Oceanic Fishery Investigations (POFI) of the U. S. Fish and Wildlife Service is surveying the tuna resources of the central equatorial Pacific. Its investigations have proven the existence of a large population of deep-swimming yellowfin tuna, Neothunnus macropterus (Temminck and Schlegel), in the vicinity of the Equator south of Hawaii. The only practicable method of sampling or harvesting these tuna is by the use of longline (also known as flagline) fishing gear, which consists of a mainline supported in the water at intervals by buoys and bearing a series of branch lines with baited hooks (Shapiro 1950). This fishing method, developed by the Japanese and used by fishermen in Hawaii, has been adopted as a sampling tool by POFI researchers.

In adapting the fishing gear used in the Hawaiian longline fishery to its purposes, POFI has introduced a number of modifications in the technique, one of the most significant of which has been a change in the kind of bait used. Hawaiian fishermen have traditionally used locally caught opelu, Decapterus pinnulatus (Eydoux and Souleyet), for bait, and have preserved it prior to fishing by packing it in rock salt (June 1950). Opelu, which brings a good price in the fresh fish market, has not often been readily available in the areas in which POFI vessels were fishing. It has, therefore, been more convenient and cheaper to use frozen West Coast sardine, Sardinops caerulea (Girard), herring, Clupea pallasii (Valenciennes), and squid, a practice which has also been followed in recent years by the Hawaiian commercial fleet.

This use of sardines and herring, and less often of squid, for longline bait has raised questions with regard to such matters as the comparative attractiveness of different baits to the various species of tuna taken on longlines, the comparative durability of the various baits while on the hook and "soaking", i.e., fishing immersed in the sea, and the effects of such preserving techniques as dry salting or brining and finally of different ways of impaling the bait on the hook. These questions are important from two points of view. First, it is desirable to determine by experimentation, if possible, what is the most effective bait and what is the best way of handling it, in order to be able to provide guidance to American fishermen who may wish to engage in tuna longline fishing. Second, it is essential to ascertain what effects, if any, variations in the kind of bait and the manner of its use have had on the catching efficiency of the gear employed on POFI fishing cruises, since the catch rates (tuna per 100 hooks per day) of this gear have been the primary index used by POFI in assessing the geographical and seasonal abundance of deep-swimming tunas. Thus the main objective of this study is to determine any adjustments that might be necessary to insure the comparability of POFI's basic longline fishing survey data.

The successful completion of the experiments was due to the efforts of the scientific personnel and crew members of the vessels Cavalieri, John R. Manning, and Hugh M. Smith. The author is also grateful to fellow staff members for their constructive criticisms of this report.

FISHING GEAR AND METHODS

The longline gear[1/] used in these experiments was made up of a number of 1,260-foot sections (known as "baskets") joined end to end to make up a set. With the exception of one experiment, each basket had 6 hook lines or droppers attached to the mainline at 180-foot intervals (fig. 1). Floats were attached by 60-foot lines at basket junctures to support the mainline. A total of 40-50 baskets were set each day at dawn and retrieved in the afternoon commencing at or shortly after noon. This procedure resulted in a range of fishing times for

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1/ Detailed accounts of the construction of the longline gear have been given by various authors (Shapiro 1950, Shimada 1951, and Niska 1953).

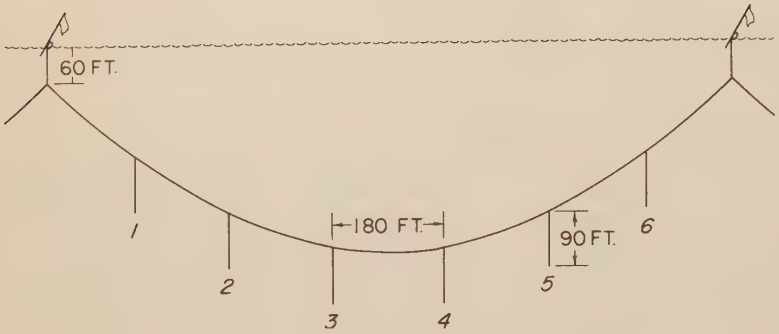

Figure 1.--Diagrammatic view of a basket of POFI longline gear.

individual baskets of 5 to 10 hours. The line was set slack in order to permit it to fish at various depths, and for this reason 40 or 50 baskets extended for only 9-10 miles.

DESIGN OF EXPERIMENTS AND TREATMENT OF DATA

Early in POFI's longline fishing program experiments were planned to compare bait species, baiting methods, and methods of bait preservation. The scope of the experimentation feasible on any one cruise was limited, e.g., to a comparison of sardine and herring, and it was soon found that the differences in catches were related mostly to soaking time and environmental conditions. Occasionally, too, it was necessary to use bait in poor condition. Therefore the experiments were designed to control statistically the effect of soaking time by alternating the variates (e.g. species or method of hooking) by baskets or groups of baskets. The environmental conditions were not controllable, but an attempt has been made to determine their effects in the analyses presented in this paper.

No single criterion is entirely satisfactory for evaluating these experiments. Of paramount concern is the effect on the catch of tuna, but in many experiments so few were caught that only gross differences could be expected to be significant. This has necessitated considerable reliance on the performance of the bait as judged by its retention on the hook.

During the course of the experimental fishing, detailed data were recorded as the line was hauled. Included in the information obtained was the soaking time of each basket and an exact record of the fate of each baited hook, i.e., the catch if any, presence or absence of bait, dropper lines broken, and fish lost during hauling.

Prior to analysis, several adjustments were made on the data as recorded in the field. Shark catches, particularly catches of the white-tipped shark, Carcharhinus longimanus (Poey)[2/], tend to obscure the effects of other factors on the bait, since many of them are captured at or near the surface during hauling. For this reason the white-tipped and the similar silky shark have been counted as "bait on". The great blue shark, Prionace glauca (Linnaeus), the third species of shark frequently caught on the longline, has been included as part of the catch as many of them have been brought alongside the vessel dead or nearly dead, indicating capture during the soaking period, and also we have not seen them at the surface in tropical waters. The other species of sharks, only occasionally encountered, have also been included as part of the catch, since little is known of their habits.

A few additional corrections were made in order to make the recorded catch represent more closely the number of fish taking the baited hooks during the soaking period. One of these was to include broken branch lines as part of the catch in those analyses involving total catch. This would have been unnecessary if the number of broken lines were a linear function of the magnitude of the total catch, however, the number of broken lines differed among stations and among cruises, not because of differences in the abundance of fish, but because of the

---

2/ The catches of the silky shark (Carcharhinus sp.) have been combined with the white-tipped shark catch because improper identification on earlier cruises does not permit separation. The results of more recent cruises in which identification was more certain show that the silky shark comprised only 23 percent of a total of 523 identified white-tipped and silky sharks.

quality of the lines. Finally, those fish lost during the hauling have been counted as part of the catch.

After these adjustments were made, the analysis was confined to a detailed examination of the catch and the bait return, and the relationships of these two variates with various methods of bait preservation, baiting methods, kinds of bait, and environmental conditions. In some instances the catches were separated and analyzed by tuna species rather than for the total catch, e.g., in the experiment on kind of bait, a separation was necessary to detect any bait preference by the different tuna species.

SOAKING TIME

As mentioned earlier, the experiments discussed in this paper were designed to control the factor of soaking time by alternating the variates by baskets or groups of baskets. The importance of time was recognized on earlier longline cruises, when it was observed that fewer baits were retrieved on the baskets that soaked longer. Actually this was to be expected, because the soaking time of the last basket of gear hauled may differ from the first by as much as 5 hours.

The results of the bait data of Manning cruise 11 (January-March 1952) are presented as an example to show the relationship of sardine bait returns with soaking time and to justify the experimental design used in the various experiments. This cruise was selected because only single-hooked sardines were used, simplifying the description. It is realized that varying results may be obtained with other types of bait and with different baiting methods, and therefore the results from the Manning cruise 11 data should be considered as solely descriptive of that cruise.

Two important effects of soaking time to be examined were: (1) whether there were any differences in the levels of the 27 station regressions of bait return with soaking time, and (2) whether there were significant differences among the slopes of the 27 regression lines. It was thought that differences in the levels of the 27 regression lines were highly probable, since the fishing stations on that cruise covered a very wide area extending from 155°W. to 180° longitude and from 8°N. to 8°S. latitude. Fishing over such a wide area involved varying fish abundance and different environmental conditions (Murphy and Shomura 1953b). As expected, the results indicated significant differences ($F = 8.43$, $P < 0.01$) among the levels of the 27 station regressions of bait return with soaking time (table 1). These differences in the levels of the station regression lines do not appear to have affected their slopes as indicated in the test for differences among regression lines (table 2). An average regression line was then calculated to represent the 27 station regression lines (table 26, fig. 2). It is clear from the slope of this line that experiments, to be meaningful, must control soaking time. As stated earlier, this was accomplished by alternating the variates by baskets or groups of baskets.

TREATMENT OF BAIT

During early POFI cruises the bait was placed in a box of rock salt for a few days prior to use to increase the firmness of the flesh and to prevent bacterial decomposition. The Hawaiian longline fishermen from whom this practice was adopted find it necessary because of the lack of mechanical refrigeration on their vessels (June 1950). Salting entails considerable effort in placing bait individually in the box of rock salt and this handling of bait in the soft, thawed-out condition increases the number of broken baits. Consequently, experiments were carried out on cruises 12 and 15 of the Manning to discover a better way of treating the bait. The three methods tested were (1) dry salting, (2) brining, and (3) untreated bait.

Table 1.--Analysis of covariance and test of significance of adjusted station means, soaking time vs. bait return, John R. Manning cruise 11 (based on data in table 24)

Source of variation	Degrees of freedom	Sum of squares and products			Sum of squares	Degrees of freedom	Mean square
		Σx^2	Σxy	Σy^2			
Total	215	5580.50	-1821.10	5316.44	4722.16	214	-
Stations	26	76.33	-189.85	2653.06	-	-	-
Within stations	189	5504.17	-1631.25	2663.38	2179.93	188	11.60
For test of significance of adjusted means					2542.23	26	97.78

$$F = \frac{97.78}{11.60} = 8.43^{**}{}^{1/}, \quad P < 0.01$$

1/ Symbols used hereafter are:

* P significant at 5-percent level.
** P significant at 1-percent level.

Table 2.--Analysis of errors of estimate from average regression within stations (based on data in tables 1, 24, and 25)

Source	Degrees of freedom	Sum of squares	Mean square
Deviation from average (error) regression within stations	188	2179.93	-
Deviation from indiv. sta. regression	162	1941.79	11.99
Diff. among regression lines	26	238.14	9.16

$$F = \frac{9.16}{11.99} = 0.76, \quad P > 0.05$$

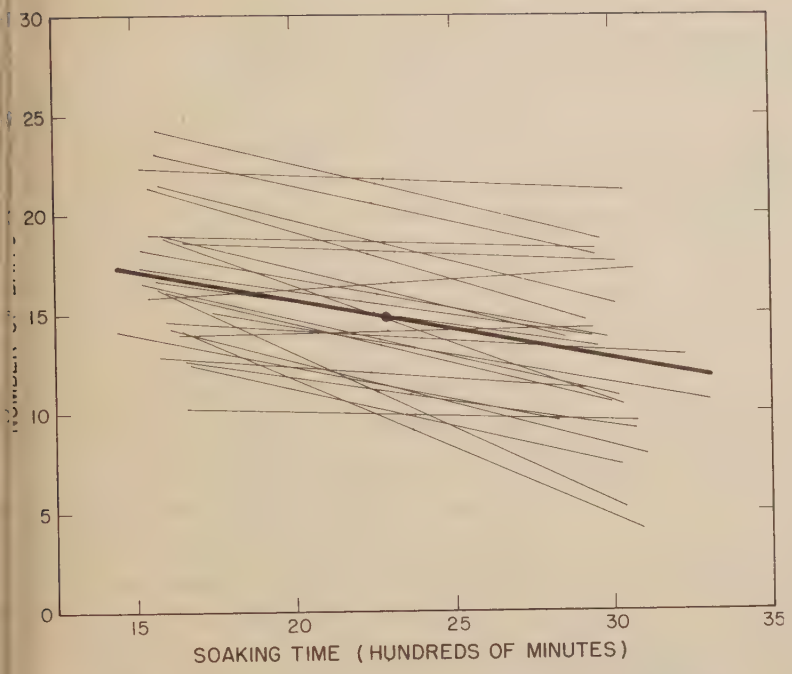

Figure 2.--Sardine bait return vs. soaking time, John R. Manning cruise 11. (Data presented in groups of 5 baskets.)

First, on cruise 12 (August-September 1952) an experiment was carried out with sardines to determine whether brined baits held up under fishing conditions as well as dry-salted baits. Brining was tried first because it involves less work and handling and yet should have the same preservative effect as dry salting. During the experiment some of the baits were brined by placing them in a saturated salt solution overnight (dry salting was done as described above). The bait returns from 720 hooks are given in table 3. The nonsignificance of the total, pooled, and interaction chi-squares ($P > 0.05$) indicates no difference in bait return under the two treatments. The division of the catch is also consistent with the similarity of bait returns, for of a catch of 21 fish 11 were caught with dry-salted sardines.

The second experiment, carried out on cruise 15 (May-June 1953), was designed to compare untreated and dry-salted baits. The results of this experiment are given in table 4. The lack of significant differences in bait return and catch with the two methods of preparation gives strong support to the idea that salting is unnecessary if refrigeration is available.

It appears that insofar as fishing efficiency is concerned there are no differences among dry-salted, brined, and fresh-thawed sardines. However, it should be pointed out that the experiments were confined to sardine baits and were carried out with a maximum soaking time of approximately 10 hours. Differences with bait treatment may appear during longer soaking periods or with different species of bait.

BAITING METHODS

In some instances small catches were coincident with small bait returns, and if these were causally related, the implication would be that an excessive number of baits had been lost during the soaking period. Under these circumstances the catch rate would not be indicative of the relative abundance of fish. To investigate this relationship and to discover ways of reducing bait loss, the usually single-hooked baits were impaled in various ways considered likely to improve the chances of their staying on the hook. The methods of baiting employed during these experiments are illustrated in figure 3. The experiments were conducted with sardine and herring. Because of anatomical differences that affect the tendency of the bait to remain on the hook, the sardine and herring experiments are considered separately.

Table 3.--Chi-square analysis of salted and brined sardine bait returns and summary of catch, John R. Manning cruise 12 (based on a total of 120 hooks for each treatment per station)

Station	Bait return		Total	χ^2
	Salted	Brined		
17	56	45	101	1.20
18	54	52	106	0.04
19	95	87	182	0.35
				1.59 Total χ^2 (3 d.f.)
Total	205	184	389	1.13 Pooled χ^2 (1 d.f.)
				0.46 Interaction χ^2 (2 d.f.)

Station	Total catch		Total
	Salted	Brined	
17	5	4	9
18	6	4	10
19	-	2	2

Table 4.--Summary of chi-square analyses of sardine bait return and catch by treatment (salted vs. fresh-thawed), John R. Manning cruise 15[1] (based on a total of 1,650 hooks per treatment; table 27)

	Source	Bait return		χ^2	Degrees of freedom
		Salted	Fresh-thawed		
Bait return	Total	-	-	3.76	14
	Pooled	1049	1039	0.05	1
	Interaction	-	-	3.71	13
Catch[2]	Total	-	-	9.46	10
	Pooled	91	115	2.80	1
	Interaction	-	-	6.66	9

[1] This and a number of subsequent tables include only summaries of the chi-square analyses. The individual analyses are similar to that presented in full in table 3.

[2] Stations have been combined to give expected values greater than 5.

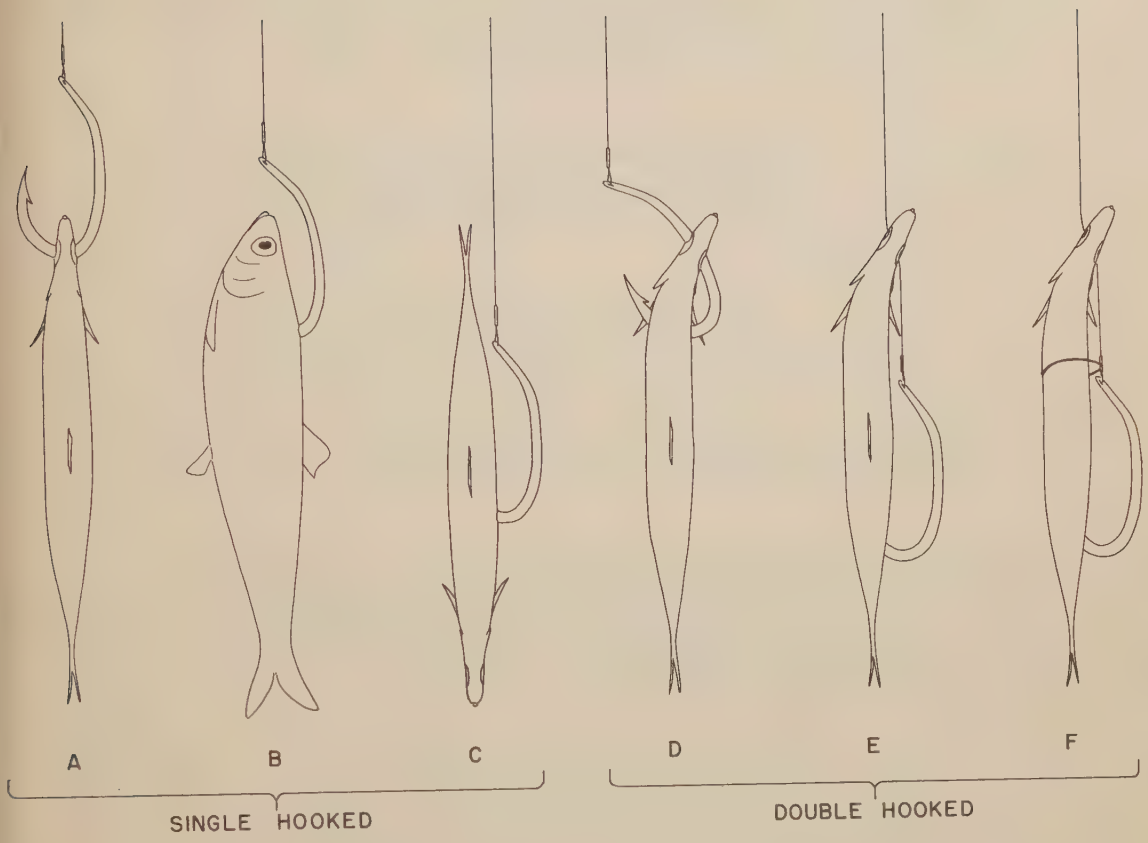

Figure 3.--Six methods of baiting.

Sardine

Two experiments comparing single hooking with two variations of double hooking were carried out on John R. Manning cruise 12. The first experiment was conducted on station 1 by alternating, by baskets, single-hooked sardines (fig. 3a) with double-hooked sardines (fig. 3e) for the entire set of 40 baskets. Of 120 baits recovered, 57 were single-hooked and 63 double. The lack of difference in bait returns is reflected in the catches, which consisted of 12 and 9 fish respectively. The experiment on station 6 was similar to that carried out on station 1 except that the double-hooked baits were fastened to the leader with rubber bands (fig. 3f). Because of the difficulty of baiting in this fashion, there were 3 times as many baskets (30 to 10) with single-hooked baits. Based on this ratio, there was a significantly higher number of double-hooked bait returns, as shown in table 5. The data on the catch (table 5) were insufficient for an analysis, but indicate no difference in catch with method of baiting.

A more extensive experiment conducted on Manning cruise 18 (December 1953) used sardines as bait and employed the single and double hooking methods illustrated in figures 3a and 3d. The results, given in table 6, show a definite advantage for double hooking in terms of bait return. Despite the higher bait returns from double hooking, it appears from the data in table 6 that the catch was not affected. This is an indication that a large part of the single-hooked sardine loss occurs during hauling, for if the loss occurred during the soaking period, it should be reflected in the catch. More direct evidence that baits are actually lost during hauling is furnished by observations made by the author on several of the longline cruises discussed in this report. From a total of approximately 1,500 baskets observed during the hauling operation, 55 sardine baits were

seen to fall off while the droppers were being retrieved. It is thought likely that an even greater number of sardines may have pulled loose before the hooks became visible to the observer. There is no evidence to indicate that the rate of loss during hauling increases with soaking time.

Table 5.--Sardine bait return and total catch by method of baiting (single vs. double), station 6, John R. Manning cruise 12 (based on a total of 180 single-hooked baits and 60 double-hooked baits)

	3:1 ratio		Total	χ^2
	Single	Double		
Bait return	103	52	155	6.04*
Catch	9	2	11	-

Table 6.--Summary of chi-square analyses of sardine bait return and total catch by method of baiting (single vs. double), John R. Manning cruise 18 (based on a total of 1,260 hooks per method of baiting; table 28)

	Source	Method of baiting		χ^2	Degrees of freedom
		Single	Double		
Bait return	Total	-	-	98.17**	14
	Pooled	682	1064	83.58**	1
	Interaction	-	-	14.59	13
Total catch[1/]	Total	-	-	7.01	6
	Pooled	72	59	1.29	1
	Interaction	-	-	5.72	5

1/ Stations have been combined to give expected values greater than 5.

Herring

On Manning cruise 14 (January-March 1953) a single vs. double hooking experiment was carried out on eight fishing stations using herring. The method of double hooking was similar to that of the sardine experiment on station 1 (fig. 3e) of Manning cruise 12, which has already been discussed. The analyses of both bait return and catch are shown in table 7. The higher return of the double-hooked herring is statistically significant as indicated by the total and pooled chi-squares (both P values less than 0.01). The double-hooked returns ranged from 1.3 to 7.4 times as many as for single-hooked herring. The heavy loss of single-hooked baits appears to be reflected in the size of the catches, for the significant pooled chi-square of 4.76 ($P < 0.05$) indicates a tendency for more fish to be caught on the double-hooked baits (table 7). However, this should not be taken as conclusive evidence in view of the following experiment carried out on the Cavalieri cruise (August-September 1952).

Table 7.--Summary of chi-square analyses of herring bait return and total catch by method of baiting (single vs. double), John R. Manning cruise 14 (based on a total of 432 hooks per method of baiting; table 29)

	Source	Method of baiting		χ^2	Degrees of freedom
		Single	Double		
Bait return	Total	-	-	67.57**	8
	Pooled	94	233	59.09**	1
	Interaction	-	-	8.48	7
Total catch[1/]	Total	-	-	9.22	5
	Pooled	32	52	4.76*	1
	Interaction	-	-	4.46	4

1/ Stations have been combined to give expected values greater than 5.

The results of the single vs. double hooking experiment (fig. 3a and 3e) conducted on the Cavalieri cruise are presented in table 8. A significant advantage for double hooking appears in the bait returns but not in the catch. However, an analysis of the catches resulted in a significant interaction chi-square of 14.34 ($P < 0.05$), which can be traced to the reversals of catch on stations 11 and 12 (table 30). At present no explanation can be advanced for this discrepancy in the catches.

Table 8.--Summary of chi-square analyses of herring bait return and total catch by method of baiting (single vs. double), Cavalieri cruise (based on a total of 1,308 hooks per method of baiting; table 30)

	Source	Method of baiting		χ^2	Degrees of freedom
		Single	Double		
Bait return	Total	-	-	288.43**	6
	Pooled	358	973	284.17**	1
	Interaction	-	-	4.26	5
Total catch	Total	-	-	14.36*	6
	Pooled	80	82	0.02	1
	Interaction	-	-	14.34*	5

Another experiment was conducted on the Cavalieri testing five different methods of baiting. Three of these were variations of single hooking and the other two were different double hooking methods (fig. 3a, b, c, d, and e). As in all of the other experiments, the bait returns showed a significant difference with method of baiting (table 9), the double-hooked baits giving higher returns. The catches of the two stations concerned were too small for analysis.

Table 9.--Chi-square analysis of five methods of baiting herring and a summary of total catch, Cavalieri cruise (based on a total of 120 hooks per method of baiting)

Bait return

Station	Single			Double		χ^2
	Eye	Head	Body	Eye and head	Eye and body	
1	19	29	24	49	33	17.04**
2	11	26	20	43	29	21.66**
						38.70** Total χ^2 (8 d.f.)
Total	30	55	44	92	62	38.01** Pooled χ^2 (4 d.f.)
						0.69 Interaction χ^2 (4 d.f.)

Total catch

Station	Single			Double	
	Eye	Head	Body	Eye and head	Eye and body
1	5	4	1	1	2
2	2	2	2	2	2
Total	7	6	3	3	4

In summarizing the results of the baiting experiments, it appears that the significantly higher returns of double-hooked sardines were due to loss of the single-hooked baits during the hauling operation. The evidence for this statement is the lack of difference in the catches by the two methods. In the case of the herring the difference in returns is of a greater magnitude, almost 3 times as many double-hooked as single-hooked herring have been retrieved, and furthermore it appears that a portion of the differential loss of single-hooked herring occurs during the soaking period, as indicated in one experiment (table 7) by the lower catches on single-hooked baits. Obviously this difficulty can be overcome by double hooking the herring.

KIND OF BAIT

Food studies undertaken by various authors (Kishinouye 1917, Nakamura 1950 and 1952, and Reintjes and King 1953) indicate that almost any pelagic marine organism of a suitable size may become food for tuna. However, a survey of the literature showed only a few experiments directed to a study of food preferences of the tunas by using different kinds of bait. One experiment conducted in 1951 on the Japanese research vessel Sagami Maru (Anonymous 1952) resulted in the general conclusion that the various tunas and marlins do not discriminate between frozen saury, Colalabis saira (Brevoort), and salted sardine, Sardinia melanostica (Temminck and Schlegel). Murphy and Otsu (1954), in their analysis of the catches of Japanese mothership expeditions, reached the same conclusion from a comparative study of the catch rates made by these two baits.

Further experiments were carried out by POFI to determine whether there were differences in catch rates with four kinds of bait, and if so to ascertain whether the differences were due to preference on the part of the fish or to superiority of the bait with respect to staying on the hook. The three experiments compared mullet vs. herring, sardine vs. squid, and sardine vs. herring.

Mullet vs. Herring

A limited experiment was conducted on Smith cruise 5 (July 1950) alternating, by baskets, mullet (Mugil vaigiensis Quoy and Gaimard and M. longimanus Günther) and herring for the entire set of 30 baskets[3/]. Table 10 gives the results of the chi-square analysis of the yellowfin catch from this experiment. The reversals of the catch with the kind of bait indicate an absence of bait preference, although the total catch shows a higher number of yellowfin caught with mullet. Since data on bait return are not available for this cruise, it is not possible to determine whether the interaction shown in table 10 ($\chi^2 = 5.96$, $P < 0.05$) was due to differences in retention of the two bait species.

Table 10.--Chi-square analysis of yellowfin catch by herring and mullet baits, Hugh M. Smith cruise 5 (based on 90 hooks per bait per fishing station)

Station	Herring	Mullet	χ^2
2, 3	3	14	7.12**
4, 5	14	11	0.36
			7.48* Total χ^2 (2 d.f.)
Total catch	17	25	1.52 Pooled χ^2 (1 d.f.)
			5.96* Interaction χ^2 (1 d.f.)

Sardine vs. Squid

A more extensive experiment alternating, by basket, salted sardine and frozen squid (probably Loligo opalescens Berry) for 50 baskets was carried out at 25 stations on cruise 13 of the Manning (October-November 1952). The chi-square analyses, testing for differences in catch and bait return, are given in table 11. A study of the total catch by the two kinds of baits shows a significantly higher number of fish caught on the sardine baits (pooled $\chi^2 = 4.60$, $P < 0.05$). However, the significance of the statistical test only indicates a tendency for more fish to be caught with sardine, since the total chi-square is nonsignificant ($P > 0.05$). Before attributing this difference to bait preference, bait availability must be considered. An analysis of the bait returns showed that more squid remained on the hooks, and the difference gave highly significant total and pooled chi-squares ($P < 0.01$). However, the interaction chi-square was also significant ($P < 0.01$), indicating the presence of a factor or factors not accounted for. The bait returns (table 31) show that squid were retrieved in greater numbers than sardine on all but five stations. A possible reason for the reversals is discussed in a later section.

Examination of the results by species of catch indicates some variation in the effectiveness of the two baits (table 11). Of a total of 135 yellowfin, 77 were caught on sardine and 58 on squid baits. However, the difference of 19 yellowfin was not statistically significant ($P > 0.05$); thus no preference can be established. The analysis of bait return at stations with yellowfin catches showed that 1.3 times more squid than sardine remained on the hooks, the total, pooled, and interaction chi-squares being significant ($P < 0.01$).

3/ The gear used on this early cruise differed in some respects from that used on subsequent cruises. Each basket had five branch lines of varying lengths (two 72 feet, two 132 feet, and one 252 feet) attached at equal intervals to a mainline section of 1,440 feet.

Table 11.--Summary of chi-square analyses of bait return and catch by kind of bait (sardine vs. squid), John R. Manning cruise 13 (based on data in table 31)

	Number of hooks per kind of bait	Source	Bait return		χ^2	Degrees of freedom
			Sardine	Squid		
All stations	3,750	Total	-	-	187.31**	25
		Pooled	2135	2831	97.55**	1
		Interaction	-	-	89.76**	24
Yellowfin	3,000	Total	-	-	163.69**	20
		Pooled	1647	2190	76.84**	1
		Interaction	-	-	86.85**	19
Bigeye	1,650	Total	-	-	73.03**	11
		Pooled	981	1290	42.04**	1
		Interaction	-	-	30.99**	10
Skipjack	1,650	Total	-	-	87.40**	11
		Pooled	934	1239	42.80**	1
		Interaction	-	-	44.60**	10

	Source	Total catch1/		χ^2	Degrees of freedom
		Sardine	Squid		
Total catch	Total	-	-	16.56	21
	Pooled	185	146	4.60*	1
	Interaction	-	-	11.96	20
Yellowfin	Total	-	-	5.15	10
	Pooled	77	58	2.67	1
	Interaction	-	-	2.48	9
Bigeye	Total	-	-	9.23**	2
	Pooled	22	6	9.14**	1
	Interaction	-	-	0.09	1
Skipjack	Total	-	-	4.00	2
	Pooled	9	19	3.57	1
	Interaction	-	-	0.43	1

1/ Stations were combined to give expected values greater than 5.

Although the catch of the bigeye tuna, Parathunnus sibi (Temminck and Schlegel), was small, the evidence--as given by significant total and pooled chi-squares ($P < 0.01$)--suggests a preference for sardine over squid baits. Of a total catch of 28 bigeye tuna, 22 were caught with sardine. The evidence for preference is further strengthened by the total bait return of 981 sardines as compared to 1,290 squids. However, this conclusion should be taken with reservations in view of the significant interaction between baits and the small catch of bigeye.

Of a total catch of skipjack, Katsuwonus pelamis (Linnaeus), of 28 only 9 were taken on sardine baits. This is a reversal of the findings for bigeye discussed above. However, the difference of 10 fish was not statistically significant.

The albacore, Germo alalunga (Gmelin), catch of 22 was almost equally divided between sardine and squid baits, with catches of 10 and 12 respectively.

Sardine vs. Herring

Experiments were conducted on Manning cruise 14 and Smith cruise 18 (October-November 1952) to test for differences between sardine and herring, the most common baits available to U. S. fishermen. On the Manning cruise both types of baits were single-hooked through the eyes, whereas on the Smith cruise the herring were double-hooked.

A summary of the analyses for the Manning experiment testing single-hooked sardines and herring is given in table 12. The results are arranged in accordance with the catch, i.e., when considering total catch the bait returns for all stations are utilized, and the bait analyses for individual species are based only on those stations at which the particular species were taken. Considering the total catch, 95 fish were caught with sardine and only 77 with herring, but the difference was statistically non-significant ($P > 0.05$) even though 3.5 times as many sardine as herring were retrieved. As in the previous experiment on sardine and squid, there was a significant interaction chi-square ($P < 0.01$). A study of the individual tuna species shows that more yellowfin, bigeye, and albacore were caught on sardine. However, the statistical tests showed that only in the case of the albacore was the catch on sardine significantly higher than the catch on herring (pooled $\chi^2 = 7.20$, $P < 0.01$). Of a total of 20 albacore caught, only 4 were taken on herring. The great difference in bait return at stations with albacore catches (4.6 times as many sardine as herring) suggests that this difference in catch may be attributable to a differential availability of the two baits during the fishing period, and that the nearly equal catch of yellowfin and bigeye was the result of a smaller differential in bait return. This then suggests that the factor(s) responsible for the differential availability of bait changed in intensity from station to station.

The second experiment on sardine and herring (Smith cruise 18) does not parallel that carried out on the Manning, for in this trial the herring were double-hooked and the sardine single-hooked. The similarity of the bait returns in this instance (table 13) clearly indicates that double hooking overcomes the differential loss of herring. The total catch and the catches of the individual tuna species show virtually no differences between the two kinds of bait.

It is evident that the bait return is a function of loss during fishing plus loss during setting and hauling. It appears that at times differential loss during hauling is responsible for differences in returns, e.g., in the single- and double-hooked sardine experiment the differences in bait return are not reflected in the catch. At other times, usually characterized by very high differential returns, e.g., in the single- and double-hooked herring experiment, the differential loss is reflected in the catch, indicating that part of the bait loss occurred during the soaking period. Indication of a further confounding factor in the experiments is the shift in relative return within an experiment (cruise). This is shown, for instance, in the presence of interaction in bait return in some of the groups of data in table 12, and its absence in others. An explanation of this phenomenon is advanced in the following section on environmental factors.

ENVIRONMENTAL FACTORS

Thus far only certain physical factors of baiting and the baits themselves have been considered in determining bait loss. Bait stealers (tunas, small fish, and invertebrates) and sea conditions also appear to affect the bait during the soaking and retrieving periods.

Bait Stealing

The larger tunas themselves have been noted to take more than one bait, as indicated by the results of stomach examinations shown in table 14. Of a total of 822 stomachs examined, 695 (84.5 percent) contained no bait fish, 112 (13.6 percent) contained one bait, and 15 (1.8 percent) held two or more baits. This would indicate that in most cases the bait is lost at the time of capture. Even

Table 12.--Summary of chi-square analyses of bait return and catch by kind of bait (sardine vs. herring), John R. Manning cruise 14 (based on data given in table 32)

	Number of hooks per kind of bait	Source	Bait return		χ^2	Degrees of freedom
			Sardine	Herring		
All stations	2,040	Total	-	-	519.91**	18
		Pooled	1178	336	468.27**	1
		Interaction	-	-	51.64**	17
Yellowfin	1,488	Total	-	-	403.40**	13
		Pooled	816	209	359.46**	1
		Interaction	-	-	43.94**	12
Bigeye	678	Total	-	-	134.63**	6
		Pooled	365	119	125.03**	1
		Interaction	-	-	9.60	5
Albacore	696	Total	-	-	199.05**	6
		Pooled	383	83	193.13**	1
		Interaction	-	-	5.92	5

	Source	Total catch1/		χ^2	Degrees of freedom
		Sardine	Herring		
Total catch	Total	-	-	19.50	12
	Pooled	95	77	1.88	1
	Interaction	-	-	17.62	11
Yellowfin	Total	-	-	3.21	6
	Pooled	38	27	1.86	1
	Interaction	-	-	1.35	5
Bigeye	Total	-	-	-	-
	Pooled	7	3	1.60	1
	Interaction	-	-	-	-
Albacore	Total	-	-	-	-
	Pooled	16	4	7.20**	1
	Interaction	-	-	-	-

1/ Stations have been combined to given expected values greater than 5.

where there is only one bait in the stomach, the possibility still exists that it might have been "stolen" from another hook prior to capture, but where there are two or more baits in the stomach they constitute firm evidence of bait stealing by tuna. An extreme case of bait stealing by tuna was observed on station 9 on cruise 16 of the Manning (July-August 1953), when 9 baits were recovered from a single yellowfin stomach.

Bait stealing by smaller fish and invertebrates has not yet been proven; however, these organisms presumably are able to feed on the longline baits without getting caught, as is indicated by partially eaten or shredded baits (fig. 4). In addition, stomach examinations of miscellaneous species of fish caught on the longline such as the barracuda, Sphyraena barracuda (Walbaum), and wahoo,

Table 13.--Summary of chi-square analyses of bait return and catch by kind of bait (sardine vs. herring), Hugh M. Smith cruise 18 (based on data in table 33)

	Number of hooks per kind of bait	Source	Bait return		χ^2	Degrees of freedom
			Sardine	Herring		
All stations	2,682	Total	-	-	127.45**	23
		Pooled	1645	1739	2.61	1
		Interaction	-	-	124.84**	22
Yellowfin	1,728	Total	-	-	109.26**	15
		Pooled	1024	1074	1.19	1
		Interaction	-	-	108.07**	14
Bigeye	1,728	Total	-	-	101.47**	15
		Pooled	987	1133	10.05**	1
		Interaction	-	-	91.42**	14
Skipjack	456	Total	-	-	35.11**	4
		Pooled	237	247	0.21	1
		Interaction	-	-	34.90**	3

	Source	Total catch1/		χ^2	Degrees of freedom
		Sardine	Herring		
Total catch	Total	-	-	10.30	13
	Pooled	116	107	0.36	1
	Interaction	-	-	9.94	12
Yellowfin	Total	-	-	0.93	4
	Pooled	29	24	0.47	1
	Interaction	-	-	0.46	3
Bigeye	Total	-	-	0.57	3
	Pooled	19	15	0.47	1
	Interaction	-	-	0.10	2
Skipjack	Total	-	-	-	-
	Pooled	4	10	2.57	1
	Interaction	-	-	-	-

1/ Stations have been combined to give expected values greater than 5.

Acanthocybium solandri (Cuvier and Valenciennes), have often revealed more than one bait, indicating their ability to take a bait without getting caught. Not much is known about bait stealing by invertebrates, however, it should be mentioned that squids are abundant in equatorial waters and may be responsible for a major share in bait losses of this type.

The loss of bait during the fishing period by bait stealing tends to lower the efficiency of the gear. It has not been possible to ascertain whether differences in the rate of bait stealing occur from station to station and cruise to cruise. Though differences must exist, it does not appear that they have appreciably affected the results of the experiments. However, within stations and experiments differences in the rate of stealing probably account for at least

Table 14.--Frequency of occurrence of one or more baits in stomachs of longline-caught yellowfin and bigeye tuna

Cruise	Number of tuna examined	1 bait	2 or more baits
Honolulu market	29	5	2
Smith - 3	1	-	-
Smith - 5	52	3	-
Smith - 7	120	16	1
Smith - 11	190	24	3
Smith - 18	57	4	2
Manning - 11	65	7	1
Manning - 12	6	2	-
Manning - 13	65	4	2
Manning - 14	88	18	2
Manning - 15	47	12	1
Gilbert - 1	61	10	-
Cavalieri	41	7	1
	822	112	15

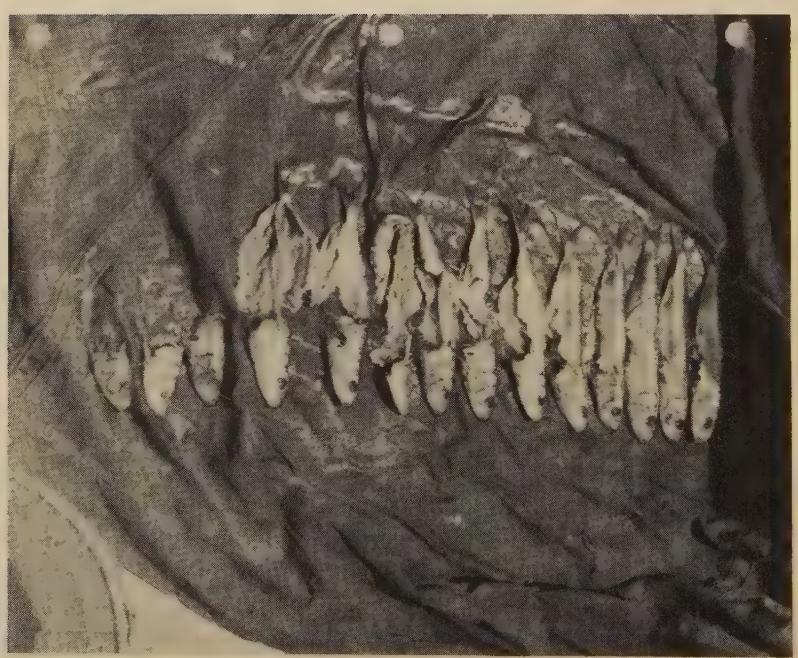

Figure 4.--Various conditions of retrieved sardine baits, John R. Manning cruise 11 (photograph by Garth I. Murphy).

some of the differences noted when comparing, for instance, sardine vs. herring and single vs. double hooking, and it follows that multiple hooking of the baits may reduce the amount of bait stealing. Double-hooked baits should withstand a greater amount of pulling before coming off than single-hooked baits, for only a slight tug and twist on a single-hooked sardine or herring will take it off the hook.

Sea Condition

Loss of bait during the fishing and retrieving period over and above that removed by animals must be the result of motion of the baited hooks. Aside from the setting and hauling periods the only source of motion is the action of the sea (ignoring movement of the line by hooked fish) during the fishing period. An indication of the effect of the motion of the sea on bait loss may be obtained from an examination of the rate of return with relative hook depth. Data from the early cruises indicated a progressive increase in the number of baits retrieved with increase in the relative hook depth (table 15). When this is considered in the light of a parallel increase in the catch with relative depth (table 16), it becomes evident that either bait stealing is less operative at greater depths or some other environmental factor or factors give the bait a better chance to remain on the deeper hooks[4/]. There is no evidence of a decrease in bait stealing with depth, but there is a possibility that the action of the sea on the gear varies inversely with depth. This could arise if the wave-induced up and down movement of the buoys were transmitted with diminishing intensity to the deeper hooks. To investigate this relationship, one end of a model longline[5/] was raised to various heights simulating the effect of wave action on the gear. Accurate measurements of the usual seas (3 to 8 feet) encountered could not be made because of the small size of the model; however, indications showed an inverse displacement of hooks with depth; e.g., a 10-foot movement gave relative motions of 1.6, 1.4, and 1.0 feet for the shallow, intermediate, and deep hooks respectively.

The effect of the sea-induced motion may also help to explain the persistently higher sardine returns as compared to the herring when considering single-hooked baits. The larger eye diameter of the herring and its relatively narrower cranial width (fig. 5) make it more apt to drop off the hook if the hook is moved up and down by the sea.

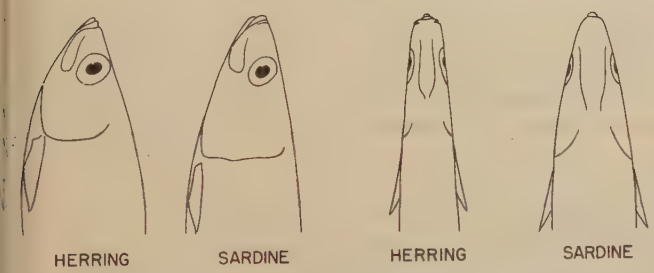

Figure 5.--Lateral and dorsal views of the sardine and herring baits.

Since it appears that loss of bait is related to relative differences in the amount of motion within sets of gear, it might be expected that under different sea conditions bait loss may vary. This is borne out by the lower returns of single-hooked sardines with increasing sea intensities (fig. 6, table 17). If the sea varies during the course of experiments on type of bait and method of hooking, the relative returns should be different under different sea intensities. In the following sections, the experiments are re-examined to ascertain whether the significant interaction chi-squares noted in several experiments could have been caused by changes in relative bait retention induced by variations in sea intensity.

4/ The problem of whether increased catch at greater depths is a function of better bait return is not under consideration. However, it is evident from a comparison of tables 15 and 16 that the catch increased more rapidly with depth than the bait return, indicating some independence of the two events.

5/ The longline model was made of chain and was proportional to the dimensions of the real gear. The chain was allowed to sag freely giving a catenary curve like that assumed to exist during fishing.

Table 15.--Bait return by the relative depth of hooks, Hugh M. Smith cruise 11, August-September 1951 (based on a total of 80 hooks per depth at each station)

Station	Shallow hooks (1 and 6)	Intermediate hooks (2 and 5)	Deep hooks (3 and 4)	Sea condition
1	19	33	29	3
2	14	22	36	2
3	31	46	60	2
4	31	36	37	3
5	28	41	40	2
6	51	59	51	1
7	39	53	50	2
8	32	34	43	1
9	19	32	40	1
10	23	21	21	3
11	26	26	27	3
12	46	35	38	2
13	28	37	42	2
15	45	50	51	2
16	38	29	40	3
17	36	34	46	1
18	49	48	51	2
19	31	39	38	2
20	18	27	34	3
21	25	43	43	3
22	25	21	27	2
23	36	36	33	2
24	55	51	61	3
25	25	43	48	3
26	20	43	44	3
27	24	39	44	2
28	18	38	34	2
Total	832	1015	1108	
$\bar{x}$	30.8	37.6	41.0	

Table 16.--Summary of catch by relative depth, Hugh M. Smith cruise 11

Species	Shallow	Intermediate	Deep
Yellowfin	115	165	175
Bigeye	13	31	49
Albacore	-	3	4
Skipjack	3	12	8
Others[1/]	20	8	11
Total	151	219	247

1/ Excluding sharks.

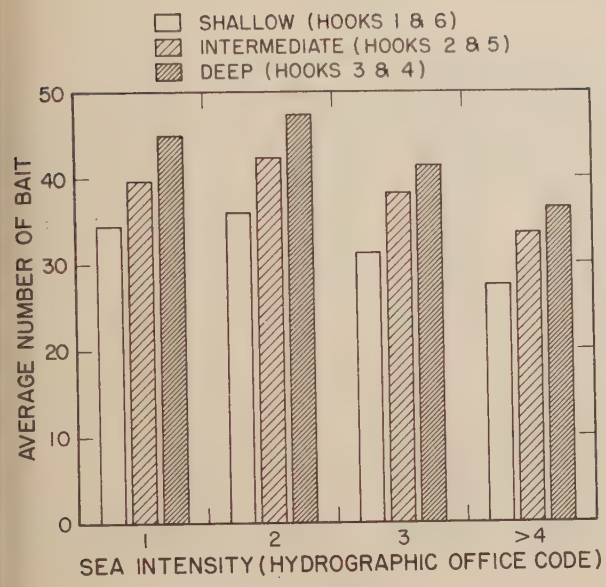

Figure 6.--Sardine bait return by relative hook depth, Hugh M. Smith cruise 11 and John R. Manning cruise 11.

Effect of Sea on Different Kinds of Bait

The presence of unaccounted factor(s) affecting the bait returns in the preference experiments was indicated by the significant interaction chi-squares (tables 11, 12, and 13). Table 18 presents the bait returns for the sardine vs. squid experiment tabulated by sea condition. The analysis of variance shows significant differences with kind of bait and a significant interaction between baits under different sea conditions. From the bait return means given in table 18 the interaction can now be attributed to the combination of the relatively stable squid returns regardless of the sea intensity and a precipitous decrease in sardine bait returns with increasing seas. This is consistent with the physical characteristics of the two baits. The tough, fibrous squid are not likely to work free, while the more delicate sardine can easily work off the hook.

The results of the rearranged data for catches made with sardine and squid as given in table 19 present a peculiar situation. The chi-square analysis of catches made in 1 and 2 seas was non-significant in all respects. In the analysis of catch for sea intensities greater than 2, the difference in catch by the two baits was significant (pooled $\chi^2 = 4.79$, $P < 0.05$) with 123 fish caught with sardine baits of a total catch of 214 fish. This then, means a significant increase in the catch on sardine as compared to squid with increasing sea intensity, even though it appears that sardines do not stay on the hook as well in higher seas. No explanation is advanced at this time except to suggest a possible change in the relative attractiveness of the two baits with increasing seas. This could be the result of the silvery sardine's being visible for a relatively greater distance when moved up and down in a rough sea.

Table 17.--Sea conditions (Hydrographic Office code)

Beaufort code	Approximate height of sea
0	0
1	less than 1 foot
2	1 - 3 feet
3	3 - 5 feet
4	5 - 8 feet
5	8 - 12 feet
6	12 - 20 feet
7	20 - 40 feet
8	40 feet and over
9	confused

Table 18.--Analysis of variance of bait return by kind of bait and sea condition, John R. Manning cruise 13 (based on data in table 31)

	Sea condition							
	0-2		3		4		5	
	Sardine	Squid	Sardine	Squid	Sardine	Squid	Sardine	Squid
	110	126	91	133	96	114	90	128
	88	125	97	136	44	100	71	97
	92	118	94	117	69	116	46	93
	118	114	122	118	62	119		
	111	81	99	82	53	118		
	114	110	69	111				
	85	112	79	120				
	114	130	68	112				
			53	109				
n	8	8	9	9	5	5	3	3
Total	832	916	772	1038	324	567	207	318
$\bar{x}$	104.0	114.5	85.8	115.3	64.8	113.4	69.0	106.0

Analysis of variance				
Source	Degrees of freedom	Sum of squares	Mean square	F
Sea condition	3	3486.64	1162.21	1.44
Bait	1	9912.32	9912.32	12.30*
Sea condition - bait interaction	3	2417.96	805.99	2.87*
Within subclasses	42	11781.56	280.51	

The results of the experiment on Manning cruise 14, testing the differences between single-hooked sardine and herring, have been re-examined in the light of changes in the environment (tables 20 and 21). The analysis of variance of bait return (table 20) shows significant differences with sea condition and between kinds of bait. Consideration of sea height appears to have eliminated the interaction noted in the original analysis (table 12). The means in table 20 indicate a progressive decrease in the returns of both baits with higher seas. Furthermore, it is to be expected that herring, which come off the hooks more easily than sardine, would be more severely affected by an increase in movement, as is indicated in table 20.

In addition to bait return, the relative catches on sardine and herring appear to be affected by variations in sea height. In 1 and 2 seas there were 2.7 times more sardine than herring retrieved, and this, combined with the identical catches made on the two baits (table 21), suggests that a large part of this higher herring loss occurred during hauling. An examination of the bait return under sea conditions above 2 shows that the difference in bait return was much greater, with 5.3 times as many sardine as herring retrieved. The analysis of the catch made with the two baits under sea conditions above 2 showed a significantly

Table 19.--Chi-square analyses of total catch by kind of bait and sea condition, John R. Manning cruise 13 (based on data in table 31)

Sea condition 0 - 2				
Station	Sardine	Squid	Total	χ^2
1	6	5	11	0.09
7	5	7	12	0.33
8	8	5	13	0.69
9	6	5	11	0.09
11	13	16	29	0.31
14	11	8	19	0.47
16	8	4	12	1.33
18	5	5	10	0.00
	62	55	117	3.31 - Total χ^2 (8 d.f.) 0.42 - Pooled χ^2 (1 d.f.) 2.89 - Interaction χ^2 (7 d.f.)

Sea condition higher than 2				
Station	Sardine	Squid	Total	χ^2
2	6	4	10	0.40
3	11	4	15	3.27
4	5	6	11	0.09
6, 10	12	7	19	1.32
15	6	9	15	0.60
17, 19	21	12	33	2.45
20	13	7	20	1.80
21	7	6	13	0.08
22	7	3	10	1.60
23	6	6	12	0.00
24	12	6	18	2.00
25	8	13	21	1.19
26, 27, 28	9	8	17	0.06
	123	91	214	14.86 - Total χ^2 (13 d.f.) 4.79* - Pooled χ^2 (1 d.f.) 10.07 - Interaction χ^2 (12 d.f.)

igher catch with sardine baits (pooled $\chi^2 = 3.96$, $P < 0.05$). Of a total catch of 3 fish, 45 were taken on sardine. This indicates that a significant portion of he higher herring loss during rough seas occurred during the fishing period.

In contrast to the above, analyses of the re-examined data from the ardine vs. herring experiment of Smith cruise 18 showed no differences in bait eturn or catch between the two kinds of bait under different sea intensities tables 22 and 23). As stated previously, this was probably the result of double ooking the herring, thus overcoming their tendency to fall off the hooks.

Table 20.--Analysis of variance of bait return by kind of bait and sea condition, John R. Manning cruise 14 (based on data in table 32)

	Sea condition							
	1		2		3		4	
	Sardine	Herring	Sardine	Herring	Sardine	Herring	Sardine	Herring
	92	44	80	24	71	22	53	13
	92	30	48	13	66	1	50	4
			77	44	54	18		
			74	18	61	14		
			43	29	49	11		
			72	17	69	14		
			49	14	78	6		
n	2	2	7	7	7	7	2	2
Total	184	74	443	159	448	86	103	17
$\bar{x}$	92.0	24.7	63.3	22.7	64.0	12.3	51.5	8.5

Analysis of variance				
Source	Degrees of freedom	Sum of squares	Mean square	F
Sea condition	3	2823.18	941.06	8.04**
Bait	1	19693.45	19693.45	168.15**
Sea condition - bait interaction	3	301.97	100.66	0.86
Within subclasses	28	3279.29	117.12	
Total	35	26097.89		

GENERAL DISCUSSION

Thus far the experiments have been discussed individually without any consideration of the ultimate goal of determining the best longline bait. An evaluation of the various experiments leads to the selection of the sardine as the best of the four bait species studied.

A direct comparison of the sardine with mullet cannot be made because the data on mullet are limited to a single experiment comparing mullet with herring. It should be pointed out that fresh mullet commands a good price in the Hawaiian market and would thus be an expensive bait. This does not, however, preclude the use of mullet in the equatorial region, since they possibly can be caught in large enough quantities for longline bait in the lagoons of the various atolls near the Equator.

The superiority of sardines over squid as bait is conclusive in view of the higher catches with sardines in sea intensities greater than 2. This has been tentatively attributed to the differences in the visibility of the two baits. It

Table 21.--Chi-square analyses of total catch by kind of bait and sea condition, John R. Manning cruise 14 (based on data in table 32)

Sea condition 0 - 2				
Station	Sardine	Herring	Total	χ^2
1	1	10	11	7.36
2, 7	8	5	13	0.69
8, 10	5	6	11	0.09
11	8	5	13	0.69
12	8	8	16	0.00
21	5	7	12	0.33
24	15	8	23	2.13
	50	49	99	11.29 - Total χ^2 (7 d.f.) 0.01 - Pooled χ^2 (1 d.f.) 11.28 - Interaction χ^2 (6 d.f.)

Sea condition higher than 2				
Station	Sardine	Herring	Total	χ^2
3, 4, 5	4	6	10	0.40
6, 17	13	7	20	1.80
18, 19	12	6	18	2.00
20	11	4	15	3.27
22	5	5	10	0.00
	45	28	73	7.47 - Total χ^2 (5 d.f.) 3.96* - Pooled χ^2 (1 d.f.) 3.51 - Interaction χ^2 (4 d.f.)

can be assumed that the silvery sardine would be seen at a greater distance than the colorless, nearly translucent squid at the depths fished by the longline gear, particularly when the sea causes the baits to move.

The selection of sardines over herring was based solely on the necessity of double hooking the latter to attain comparable catching efficiency. That double hooking is unnecessary for sardines was shown in the single- vs. double-hooked sardine experiment. The double-hooked sardines were retrieved in greater numbers but did not have a higher catch than the single-hooked sardine baits. On the other hand, one experiment on single- and double-hooked herring showed a higher catch with double-hooked baits. Further evidence of the superiority of the sardine was shown in the sardine vs. herring experiment in which both baits were single hooked. Relatively more sardines were retrieved when the seas were greater than force 2, and at the same time the catch on sardines was higher.

In the above discussion visibility and availability have been considered to be the principal reasons for the superiority of sardines over squid and herring. However, several peculiarities were noted in the results of the experiments. In

Table 22.--Analysis of variance of bait return by kind of bait and sea condition, Hugh M. Smith cruise 18 (based on data in table 33)

	Sea condition							
	1		2		3		4	
	Sardine	Herring	Sardine	Herring	Sardine	Herring	Sardine	Herring
	91 100	75 70	80 72 83 61 73	89 98 91 87 61	76 76 85 71 62 57 39 44 73 72 61 90 39	80 88 84 99 83 52 57 79 65 93 75 46 57	83 27 75 91	90 95 29 53
n	2	2	5	5	13	13	4	4
Total	191	145	369	426	845	958	276	267
$\bar{x}$	95.5	72.5	73.8	85.2	65.0	73.7	69.0	66.8

Analysis of variance				
Source	Degrees of freedom	Sum of squares	Mean square	F
Sea condition	3	1448.55	482.85	1.460
Bait	1	275.52	275.52	0.833
Sea condition - bait interaction	3	1079.62	359.87	1.088
Within subclasses	40	13226.12	330.65	
Total	47	16029.81		

the sardine vs. squid experiment, visibility was considered to be the factor responsible for the higher catch of yellowfin and bigeye with sardine baits. From this it might be reasoned that albacore, considered to be a very deep-swimming fish in equatorial waters, would be caught in greater numbers on sardine baits. That this was not true is shown by the almost equally divided catch of 10 albacore caught with sardine baits and 12 with squid baits. The distribution of the skipjack catch also differed from those of yellowfin and bigeye, with a catch of 19 skipjack on squid and only 9 on sardine. However, visibility is possibly not as important a factor with this surface species as it is for the deeper swimming tunas, and if this were true, differential bait retention on the shallow hooks may have been the cause of the discrepancy.

One of the objectives of this study was to determine whether the various baits and baiting methods used in tuna longline fishing modify the catch rates sufficiently to affect their comparability when used as indices of tuna abundance.

Table 23.--Chi-square analysis of total catch by kind of bait and sea condition, Hugh M. Smith cruise 18 (based on data in table 33)

Sea condition 0 - 2				
Station	Sardine	Herring	Total	χ^2
5, 9, 10	6	5	11	0.09
25	10	8	18	0.22
31	6	5	11	0.09
32	4	8	12	1.33
33	5	5	10	0.00
	31	31	62	1.73 - Total χ^2 (5 d.f.) 0.00 - Pooled χ^2 (1 d.f.) 1.73 - Interaction χ^2 (4 d.f.)

Sea condition higher than 2				
Station	Sardine	Herring	Total	χ^2
6	5	5	10	0.00
7, 8	10	10	20	0.00
12, 14	6	7	13	0.08
16	6	5	11	0.09
18, 20	15	15	30	0.00
22, 23	2	9	11	4.45
27, 29	7	5	12	0.33
30	11	7	18	0.89
35, 36, 37	23	13	36	2.78
	85	76	161	8.62 - Total χ^2 (9 d.f.) 0.50 - Pooled χ^2 (1 d.f.) 8.12 - Interaction χ^2 (8 d.f.)

It was found that the differences in the catch between hooks baited with sardine and those baited with herring (tables 12 and 13) were small and non-significant. Considered in relation to geographical and temporal variations (Murphy and Shomura 1953a, b), and in relation to random variability (Murphy and Elliott 1954) they are too small to warrant any adjustment of the catch rate data to compensate for them. The most extreme difference appeared in an experiment comparing sardine and squid (table 19), where of a total catch of 331 fish, 185 (56 percent) were taken with sardine baits. Though statistically significant, this difference is still small relative to the differences attributable to time, space, and random variability. Also these are differences of total catch of all fish, corrected for broken gear and surface sharks and not actual catches of individual species for which the variability from sources other than differences in baits might be still greater. Adjustment to compensate for the lower catching effectiveness of squid-baited longlines would appear warranted only for special types of analysis of pooled data where the bias may emerge above the other sources of variability.

SUMMARY

1. A study of bait returns shows a progressive decrease in the number of sardine baits retrieved with increasing soaking time.

2. With respect to sardine, there were no differences in catches as between salted and brined or between salted and fresh-thawed baits.

3. Of the three principal bait species studied (sardine, herring, and squid), the evidence shows the sardine to be the best longline bait. The sardine need only be single hooked, whereas the herring in order to attain equal efficiency must be double hooked. The sardine's superiority over squid is based on higher catches in moderate to rough seas. If this advantage is due to visibility, then the herring, which is similar in appearance to the sardine, should also be superior to the squid in rough seas, providing the herring are double hooked. Thus the order of preferability of the commonly available longline bait is single-hooked sardines, double-hooked herring, and finally squid.

4. The differences in the catch related to the kind of bait are not attributable to dietary preference but are explained on the basis of availability or visibility during the soaking period.

5. It is unnecessary to make adjustments to the catches made by the different species of bait and different baiting methods for POFI's general study of tuna abundance in the equatorial Pacific, because the differences in catch were small in magnitude when contrasted with other sources of variability.

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Table 24.--Total soaking time and total sardine bait return, John R. Manning cruise 11 (data combined into groups of 5 baskets)

Station number		Basket number							
		40-36	35-31	30-26	25-21	20-16	15-11	10-6	5-1
1	X[1]	17.43	19.41	21.00	22.68	26.64	29.03	30.64	23.11
	Y[2]	19	22	12	9	8	17	15	4
2	X	15.97	17.73	19.67	21.70	26.05	28.41	30.39	32.22
	Y	16	13	14	13	14	16	12	12
3	X	16.54	18.04	19.80	21.69	25.62	27.69	29.27	30.91
	Y	14	15	12	9	6	6	5	6
4	X	15.74	17.09	18.50	19.87	24.12	26.83	28.77	30.37
	Y	17	18	13	13	10	7	6	5
5	X	15.15	16.64	18.08	19.63	23.87	26.16	27.74	29.34
	Y	16	21	16	15	12	15	16	14
6	X	15.43	17.11	18.56	19.93	24.25	26.34	27.69	29.14
	Y	23	18	23	17	14	18	18	13
7	X	15.92	17.49	18.93	20.51	25.08	27.82	29.38	30.85
	Y	16	19	20	13	5	17	18	10
8	X	15.99	17.45	18.89	20.39	24.24	26.41	28.03	29.96
	Y	11	18	13	21	9	18	9	8
9	X	15.84	17.34	18.74	20.05	23.69	25.63	27.18	28.55
	Y	18	20	19	15	14	16	19	10
10	X	16.34	17.78	19.31	21.03	24.86	26.70	28.12	29.39
	Y	11	17	15	14	14	13	14	15
11	X	15.67	17.25	18.89	20.29	24.32	26.33	27.70	29.52
	Y	20	12	15	19	12	11	17	14
12	X	15.78	17.42	18.83	20.38	24.69	26.88	28.64	30.09
	Y	21	26	19	15	19	13	19	16
13	X	16.51	18.00	19.46	20.77	24.98	27.14	28.59	30.09
	Y	20	24	19	19	16	19	17	14
14	X	16.58	18.39	19.95	21.54	25.54	27.82	29.43	30.78
	Y	14	13	7	7	5	8	10	15
15	X	16.57	18.14	19.57	21.17	25.62	27.84	29.22	30.69
	Y	15	6	11	19	8	7	11	10
16	X	16.76	18.30	19.72	21.11	25.32	27.45	28.93	30.24
	Y	9	12	14	13	8	7	11	5
17	X	16.07	17.87	19.62	21.51	25.71	27.91	29.40	31.10
	Y	16	13	9	13	13	9	7	8
18	X	15.75	17.18	18.53	19.95	24.25	26.44	27.80	29.12
	Y	7	21	12	10	11	14	12	9
19	X	14.45	16.16	18.03	19.60	23.45	25.47	27.17	28.88
	Y	14	16	10	12	11	13	12	7
20	X	15.17	16.69	18.30	20.39	24.81	26.93	28.39	29.86
	Y	14	20	16	22	17	13	10	16
21	X	15.40	16.83	18.48	19.95	24.16	26.18	27.70	29.46
	Y	22	19	20	14	19	14	19	22
22	X	15.88	17.49	19.16	20.65	24.97	27.17	28.68	30.31
	Y	21	17	17	13	14	13	13	9
23	X	15.20	17.00	18.77	20.38	24.97	27.19	28.75	30.38
	Y	21	22	26	18	24	24	18	21
24	X	15.65	17.09	18.54	19.99	24.29	26.64	28.00	29.49
	Y	23	26	19	22	17	20	15	22
25	X	15.69	17.27	18.77	20.29	24.42	26.57	28.15	29.66
	Y	24	21	23	27	21	19	16	21
26	X	15.37	16.82	18.29	20.98	25.59	27.72	29.20	30.70
	Y	14	21	14	13	20	19	12	19
27	X	15.19	16.81	18.46	20.04	24.79	27.31	28.75	30.19
	Y	21	14	13	16	8	8	16	13

1/ Total soaking time in hundreds of minutes.
2/ Total bait return.

Table 25.--Analysis of covariance (total soaking time vs. total bait return), John R. Manning cruise 11

Station	d.f.	Σx^2	Σxy	Σy^2	n	b	$\Sigma d_y x^2$	d.f.
1	7	151.5972	- 43.725	259.500	-0.220	-0.2884	246.888	6
2	7	259.8793	- 27.855	17.500	-0.413	-0.1072	14.514	6
3	7	205.1665	-143.095	112.875	-0.940	-0.6975	13.066	6
4	7	220.2977	-166.700	168.000	-0.867	-0.7567	41.857	6
5	7	204.2146	- 50.521	45.875	-0.522	-0.2474	33.377	6
6	7	189.6990	- 92.680	92.000	-0.702	-0.4886	46.720	6
7	7	232.6472	- 75.265	183.500	-0.364	-0.3235	159.151	6
8	7	189.6838	- 76.450	173.875	-0.421	-0.4030	143.063	6
9	7	159.7292	- 66.312	77.875	-0.595	-0.4152	50.345	6
10	7	173.2695	∤ 3.379	20.875	∤0.056	∤0.0195	20.809	6
11	7	186.4292	- 44.640	80.000	-0.366	-0.2394	69.311	6
12	7	207.2983	- 88.215	112.000	-0.579	-0.4255	74.460	6
13	7	186.9044	- 13.712	66.875	-0.123	-0.0734	65.869	6
14	7	200.9148	- 8.666	106.875	-0.059	-0.0431	106.501	6
15	7	205.2888	- 50.368	130.875	-0.307	-0.2454	118.517	6
16	7	186.2919	- 69.731	68.875	-0.616	-0.3743	42.774	6
17	7	222.6415	- 95.430	70.000	-0.764	-0.4286	29.096	6
18	7	186.5088	- 22.760	124.000	-0.150	-0.1220	121.223	6
19	7	199.8627	- 63.249	50.875	-0.627	-0.3165	30.859	6
20	7	223.3634	- 67.560	102.000	-0.448	-0.3025	81.565	6
21	7	196.5782	- 10.780	67.875	-0.093	-0.0548	67.284	6
22	7	208.2789	-122.137	91.875	-0.883	-0.5864	20.253	6
23	7	230.3300	- 17.040	57.500	-0.148	-0.0740	56.239	6
24	7	197.6141	- 72.805	86.000	-0.558	-0.3684	59.177	6
25	7	195.8814	- 77.950	76.000	-0.639	-0.3979	44.980	6
26	7	249.3341	∤ 22.325	90.000	∤0.149	∤0.0895	88.000	6
27	7	234.4678	- 89.262	129.875	-0.512	-0.3807	95.893	6
	189	5504.1723	-1631.204	2663.375	-0.426	-0.2964	1941.791	162

Table 26.--Test of average regression coefficient from $\beta = 0$, John R. Manning cruise 11

Average regression line:

$$\hat{Y} = \bar{y} + b(X - \bar{x})$$

$$\hat{Y} = -0.2964 X + 21.585$$

Test from $\beta = 0$:

$$\Sigma d_{y.x}^2 = 2179.955$$

$$\Delta_{y.x}^2 = 10.1867$$

$$\Delta_b = 0.0430$$

$$t = \frac{b - \beta}{\Delta_b}$$

$$t = \frac{-0.2964}{0.0430}$$

$$t = -6.893^{**} \quad (P < 0.01)$$

Table 27.--Summary of sardine bait return and total catch by method of treatment (dry-salted vs. fresh-thawed), John R. Manning cruise 15

Station	Number of baskets set per treatment	Salted		Fresh-thawed	
		Bait return	Total catch	Bait return	Total catch
1	20	111	2	114	2
2	17	60	5	65	7
3	20	72	5	59	12
5	20	64	9	70	5
6	20	79	6	83	3
7	19	37	16	38	19
8	20	58	13	61	18
10	20	78	6	85	4
11	20	83	4	76	3
12	20	82	2	79	9
13	19	84	3	85	4
14	20	88	6	79	10
15	20	91	5	81	8
16	20	62	9	64	11

Table 28.--Summary of sardine bait return and total catch by method of hooking (single vs. double), John R. Manning cruise 18 (based on 15 baskets per method of baiting per station)

Station	Sea condition	Single-hooked		Double-hooked	
		Bait return	Total catch	Bait return	Total catch
2	3	42	4	70	7
5	3	39	5	71	4
8	3	36	14	67	8
10	3	69	1	81	-
12	3	62	3	76	3
14	4	40	4	72	5
16	4	44	6	75	3
18	3	33	17	66	8
19	3	65	3	78	5
21	3	50	2	80	2
23	1	61	4	83	3
25	2	39	1	85	1
27	2	46	6	80	7
29	3	56	2	80	3

Table 29.--Summary of herring bait return and total catch by method of hooking (single vs. double), John R. Manning cruise 14

Station	Number of baskets set per treatment	Sea condition	Single		Double	
			Bait return	Total catch	Bait return	Total catch
27	10	1	5	4	37	3
28	10	3	18	1	38	4
29	9	2	8	2	22	7
32	10	3	16	9	37	7
33	6	3	6	7	18	7
35	7	3	15	1	19	9
36	10	3	12	4	28	10
37	10	3	14	4	34	5

Table 30.--Summary of herring bait return and total catch by method of hooking (single vs. double), Cavalieri cruise

Station	Number of baskets set per treatment	Sea condition	Single		Double	
			Bait return	Total catch	Bait return	Total catch
11	38	2	78	32	177	15
12	35	2	75	4	162	15
13	39	2	68	11	175	17
14	39	2	61	10	180	8
15	30	2	39	8	132	9
16	37	2	37	15	142	18

Table 31.--Summary of bait return, catch, and sea condition, John R. Manning cruise 13 (based on 25 baskets per kind of bait per station)

Station	Sardine						Squid						Sea condition
	Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	
1	114	6	-	-	3	-	130	5	-	-	3	-	1
2	96	6	-	3	-	-	114	4	-	1	-	-	4
3	91	11	-	6	-	-	133	4	-	1	-	1	3
4	90	5	-	-	-	1	128	6	-	1	-	-	5
6	97	5	-	4	-	-	136	1	-	-	-	-	3
7	110	5	1	1	-	-	126	7	2	-	-	-	2
8	88	8	5	1	-	-	125	5	3	-	-	-	2
9	92	6	2	2	-	-	118	5	2	1	-	-	2
10	94	7	3	3	-	-	117	6	4	-	-	-	3
11	118	13	11	-	-	-	114	16	10	-	-	2	2
14	111	11	7	-	-	1	81	8	5	1	-	1	2
15	122	6	1	-	-	4	118	9	2	-	-	6	3
16	114	8	6	-	-	-	110	4	3	-	-	-	2
17	99	5	1	-	-	-	82	3	3	-	-	-	3
18	85	5	3	-	-	-	112	5	2	-	1	-	2
19	44	16	7	2	4	-	100	9	2	-	5	-	4
20	69	13	6	-	2	-	111	7	4	-	2	-	3
21	79	7	4	-	-	-	120	6	3	-	-	1	3
22	68	7	2	-	1	1	112	3	-	1	1	1	3
23	69	6	2	-	-	1	116	6	2	-	-	1	4
24	62	12	8	-	-	-	119	6	3	-	-	1	4
25	53	8	3	-	-	1	109	13	6	-	-	4	3
26	53	2	2	-	-	-	118	1	1	-	-	-	4
27	71	3	1	-	-	-	97	3	-	-	-	1	5
28	46	4	2	-	-	-	93	4	1	-	-	-	5

Table 32.--Summary of bait return, catch, and sea conditions, John R. Manning cruise 14

Station	Number of baskets set per kind of bait	Sardine						Herring						Sea condition
		Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	
1	19	92	1	-	-	-	-	44	10	-	-	-	-	1
2	19	92	1	-	1	-	-	30	1	-	-	-	-	1
3	18	71	-	-	-	-	-	22	1	-	-	-	-	3
4	19	53	4	-	1	-	-	13	-	-	-	-	-	4
5	20	50	-	-	-	-	-	4	5	3	-	-	1	4
6	19	66	7	5	-	-	-	1	2	2	-	-	-	3
7	20	80	7	2	-	-	1	24	4	2	-	-	-	2
8	14	48	4	4	-	-	-	13	5	3	-	-	1	2
10	18	77	1	1	-	-	-	44	1	1	-	-	-	2
11	18	74	8	7	-	-	3	18	5	3	1	-	-	2
12	20	43	8	6	2	-	-	29	8	5	1	-	-	2
17	17	54	6	-	2	1	-	18	5	-	-	-	2	3
18	20	61	6	3	-	1	-	14	3	-	-	1	-	3
19	20	49	6	3	1	-	-	11	3	1	1	-	-	3
20	20	69	11	1	-	5	-	14	4	2	-	1	1	3
21	20	72	5	1	-	2	-	17	7	2	-	1	-	2
22	19	78	5	1	-	2	-	6	5	-	-	1	-	3
24	20	49	15	4	-	5	-	14	8	3	-	-	-	2

Table 33.--Summary of bait return, catch, and sea condition, Hugh M. Smith cruise 18

Station	Number of baskets set per kind of bait	Sardine						Herring						Sea condition
		Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	
5	20	80	1	-	-	-	-	89	2	-	1	-	-	2
6	20	76	5	-	3	-	-	80	5	-	-	-	-	3
7	20	83	4	-	1	-	-	90	4	-	-	-	-	4
8	19	76	6	-	3	-	-	88	6	-	5	-	-	3
9	19	72	1	1	-	-	-	98	0	-	-	-	-	2
10	20	83	4	-	-	-	-	91	3	-	-	-	-	2
12	18	85	3	1	1	-	-	84	4	2	1	-	-	3
14	20	71	3	-	1	-	-	99	3	-	-	-	-	3
16	19	62	6	2	1	-	-	83	5	2	-	-	-	3
18	16	57	2	2	-	-	-	52	7	2	1	1	3	3
20	20	27	13	7	3	-	-	95	8	7	-	-	-	4
22	16	39	1	1	-	-	-	57	2	-	1	-	-	3
23	20	44	1	1	-	-	-	79	7	2	2	-	1	3
25	20	61	10	4	2	-	1	87	8	2	1	-	4	2
27	20	73	3	1	-	-	-	65	3	1	-	-	-	3
29	20	72	4	3	-	-	-	93	2	2	-	-	-	3
30	20	61	11	-	2	-	-	75	7	-	-	-	-	3
31	20	91	6	2	-	-	-	75	5	1	-	-	-	1
32	20	100	4	-	-	-	-	70	8	1	-	-	-	1
33	20	76	5	2	-	-	-	61	5	2	-	-	-	2
35	20	90	5	1	-	-	-	46	3	-	2	-	-	3
36	20	75	14	1	2	-	3	29	8	-	1	-	2	4
37	20	91	4	-	-	-	-	53	2	-	-	-	-	4

Longline Fishing For Deep-Swimming Tunas In The Central Pacific, 1953

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UNITED STATES DEPARTMENT OF THE INTERIOR
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Explanatory Note

The series embodies results of investigations, usually of restric
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LONGLINE FISHING FOR DEEP-SWIMMING TUNAS IN THE CENTRAL PACIFIC, 1953

By

Richard S. Shomura and Garth I. Murphy
Fishery Research Biologists
Pacific Oceanic Fishery Investigations
U. S. Fish and Wildlife Service

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This is the fourth[1/] in a series of reports on a survey of the ep-swimming tunas of the central equatorial Pacific. This survey s been conducted by the Pacific Oceanic Fishery Investigations OFI) as a portion of a larger investigation embracing the hydro- aphy and productivity of the central Pacific as well as the fishery sources (Sette MS).

Herein we summarize the salient features of six equatorial shing cruises made between 140°W. and 170°W. longitude in 1953 able 1, fig. 1). In addition, the results of a considerable amount of panese fishing in 1953 between 160°W. longitude and 180° are dis- ssed. Complete summaries of the POFI cruises and of the catch ta from the Japanese fishing are given in the appendix.

We use the vernacular names of the fishes throughout this port. These, with their commonly accepted scientific names, are sted below:

White-tipped shark, Carcharinus longimanus (Poey)
Silky shark, Carcharinus sp.[2/]
Great blue shark, Prionace glauca (Linnaeus)
Bonito shark, Isurus glaucus (Müller and Henle)
Marlin, Makaira sp.
Sailfish, Istiophorus orientalis (Schlegel)
Wahoo, Acanthocybium solandri (Cuvier and Valenciennes)
Dolphin, Coryphaena hippurus (Linnaeus)
Yellowfin tuna, Neothunnus macropterus (Temminck and Schlegel)

[1/] Fishing from July 1950 to December 1952 is summarized n Murphy and Shomura 1953a, b, and 1955.

[2/] A species closely resembling C. floridanus Bigelow, chroeder, and Springer, and C. ahenea (Stead).

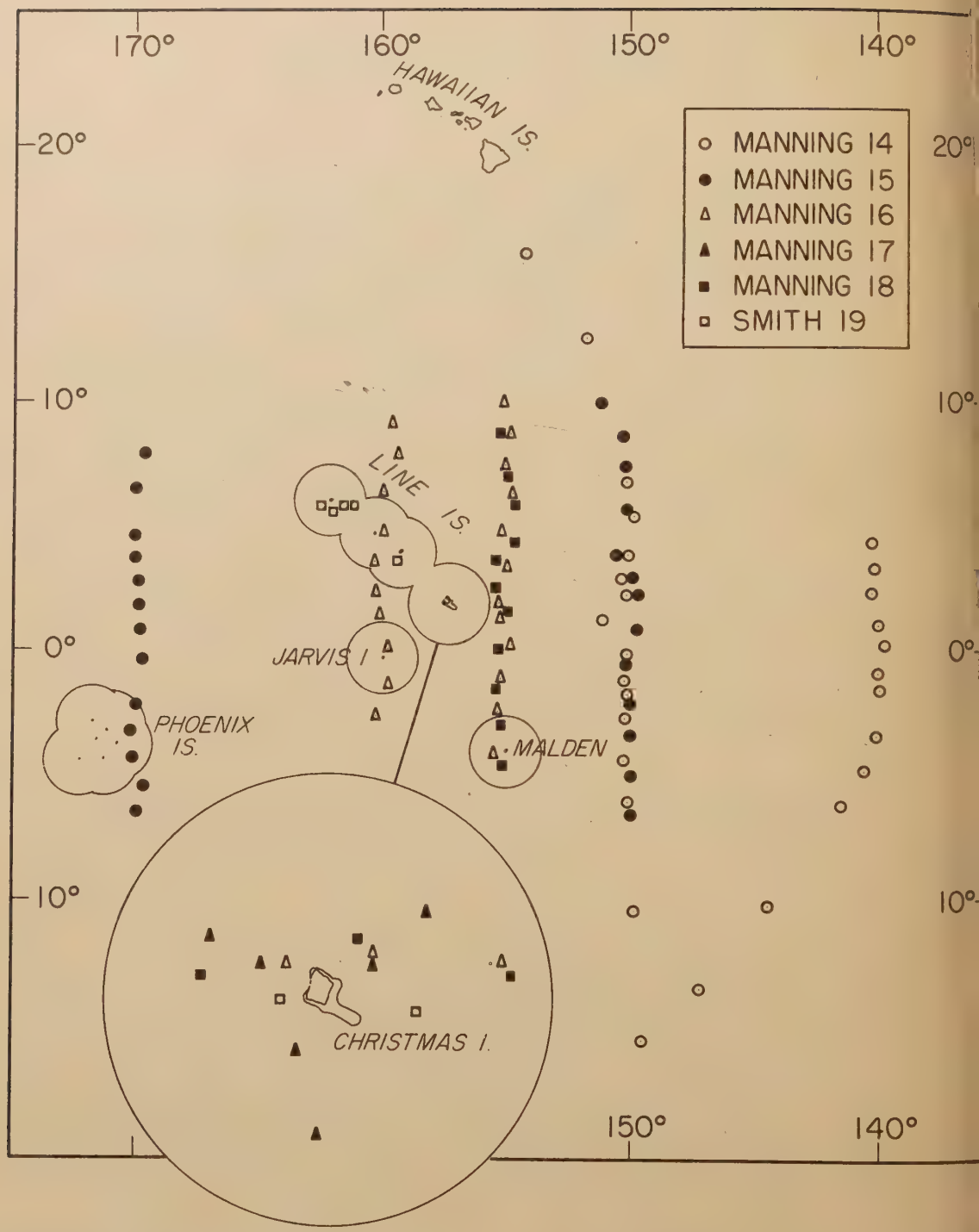

Figure 1.--Location of fishing stations during 1953, John R. Manning cruises 14 through 18, Hugh M. Smith cruise 19. The stations within 80 miles of land are enclosed in circles. Stations fished near Christmas Island appear in the insert.

Bigeye tuna, Parathunnus sibi (Temminck and Schlegel)
Skipjack, Katsuwonus pelamis (Linnaeus)
Albacore, Germo alalunga (Bonnaterre)
Lancet fish, Alepisaurus sp.
Barracuda, Sphyraena barracuda (Walbaum)

Table 1.--Period and general area of POFI longline fishing in the equatorial Pacific, 1953

Vessel and cruise	Period of operation	General fishing area
. R. Manning, cruise 14	January-March	140°W., 150°W.
. M. Smith, cruise 19	January-February	Line Islands
. R. Manning, cruise 15	April-June	150°W., 170°W.
. R. Manning, cruise 16	July-August	155°W., 160°W., and 155°W. to Christmas Island
. R. Manning, cruise 17	October-November	Christmas Island
. R. Manning, cruise 18	December	155°W., 155°W. to Christmas Island

ACKNOWLEDGEMENTS

So large a venture could hardly have been accomplished without e cooperation of most of the staff of POFI including the officers and ews of our research vessels. Miss Jean S. Halling assisted in proc-sing the catch records. The temperature sections were prepared by S. Austin and the writers.

DESCRIPTION OF GEAR AND OPERATIONAL METHODS

Descriptions of the longline gear used by POFI have appeared in evious reports (Murphy and Shomura 1953a, b, Niska, 1953) and may summarized as follows. One unit of gear, called a basket, has 260 feet of mainline and six 88-foot branch lines (droppers) attached the mainline at 30-fathom intervals. Several baskets are joined to ake up a set, the entire set being buoyed with floats at basket junc-res and at the ends. Fishing at subsurface levels is accomplished by ing 10-fathom lines between mainlines and floats and by setting the ainline slack so that it will sag in the water. To this end, the 1,260 et of mainline is set in about 900 linear feet.

Some experimental gear was fished on each of the six cruises in 1953 in order to determine whether modifications of the standard gear would decrease the labor of handling the gear or increase the catch per unit of gear. The details of each type of special gear and th results from its use will be discussed in a separate section; the discussions of distribution and abundance are based on the standard gear described above.

The daily operations during the 1953 cruises were similar to those of earlier cruises. Setting started at dawn and took a little over an hour. Either fresh frozen sardines or herring were used as bait. Hauling commenced around noon, and the last basket set was the first to be hauled. Although the total time taken for hauling differed somewhat from station to station, the line was usually all on board at about 4:30 p.m. Further details of the work schedule for each station of the several cruises are given in appendix tables 22 through 27.

DISTRIBUTION AND ABUNDANCE OF TUNAS

The fishing cruises prior to 1953 were designed to cover a wide expanse of the equatorial Pacific (180°-120°W. longitude) in order to delimit the general area in which yellowfin were most abundant.

These surveys revealed a zone of high abundance between 140° and 160°W. longitude (Murphy and Shomura 1953a, b, 1955). Within these longitudes yellowfin were most abundant in the latitudinal belt enriched by the equatorial upwelling described by Cromwell (1953), the best catches usually being made between 1°N. and 6°N. latitude.

During 1953 attention was focused on a narrower range of longitudes (140°W. to 170°W.) in order to study more effectively latitudinal and seasonal variations in yellowfin abundance in the most promising area. In addition, special studies were made of the tuna populations in the vicinity of the Line Islands (fig. 1).

In our discussion, the longline stations for 1953 are separated into two categories, oceanic and insular, the latter being those located within 80 miles of land. This separation, in part arbitrary, was made in order to determine whether the abundance and the size of longline tuna are related to the nearness of land. The line of demarcation chosen probably eliminates the influence of the islands from the oceani stations, as it seems unlikely that the presence of the small Line Islands significantly alters the environment for tuna as far as 80 miles

shore, but, on the other hand, the stations classed as insular may in ne instances be outside of any influence of the islands.

Yellowfin Tuna

In this section we shall consider variations in the location of center of abundance of oceanic yellowfin tuna in the central equa- ial Pacific during 1953. We are somewhat handicapped because npling was not adequate over the entire area during most seasons. ere are, however, clear indications that the population is not static space, and there is on hand for 1953 enough information to develop reliminary hypothesis.

The catch results presented graphically in figures 2 and 3 can st be studied by considering the temporal changes in yellowfin abun- nce first by longitude, then by latitude, and finally as an integrated ole.

In terms of longitude, during February and March yellowfin re more abundant (about 10 per hundred hooks) to the east (140°W.) an they were farther west (150°W.) (fig. 2), where about 3 were ken per hundred hooks fished. Unfortunately, there is no information om west of 150°W. for this period, so there is no way of knowing hether the trend continued in that direction unless the poor catches April near 180° are regarded as evidence that the trend did continue st (fig. 3). Later in the year, during May and June, catches of 9 llowfin per hundred hooks were made along 150°W., but the north- uth extent of the area of high catches was limited (only two stations), hile on 170°W. a much wider band of good fishing (around 7 per hun- ed hooks) was found, suggesting that there were more yellowfin west 150°W. The concentration encountered on 170°W. evidently extended least as far as 180°, for Japanese commercial boats experienced tches averaging over 5 yellowfin per hundred hooks between 170°W. d 180° (fig. 3). During August the highest catches (about 10 per hun- ed hooks) were made on 155°W. (fig. 2), and poorer fishing (less than per hundred hooks) was found farther west between 160°W. and 180° igs. 2 and 3), suggesting an eastward shift of the population from its cation during May and June. Finally, during December poor catches bout 2 per hundred hooks, with one exception) were had along 155°W. ig. 2), but there is no information from areas east or west of that ngitude so we cannot hazard a guess as to the location of the center abundance, if one existed, along the Equator at that time.

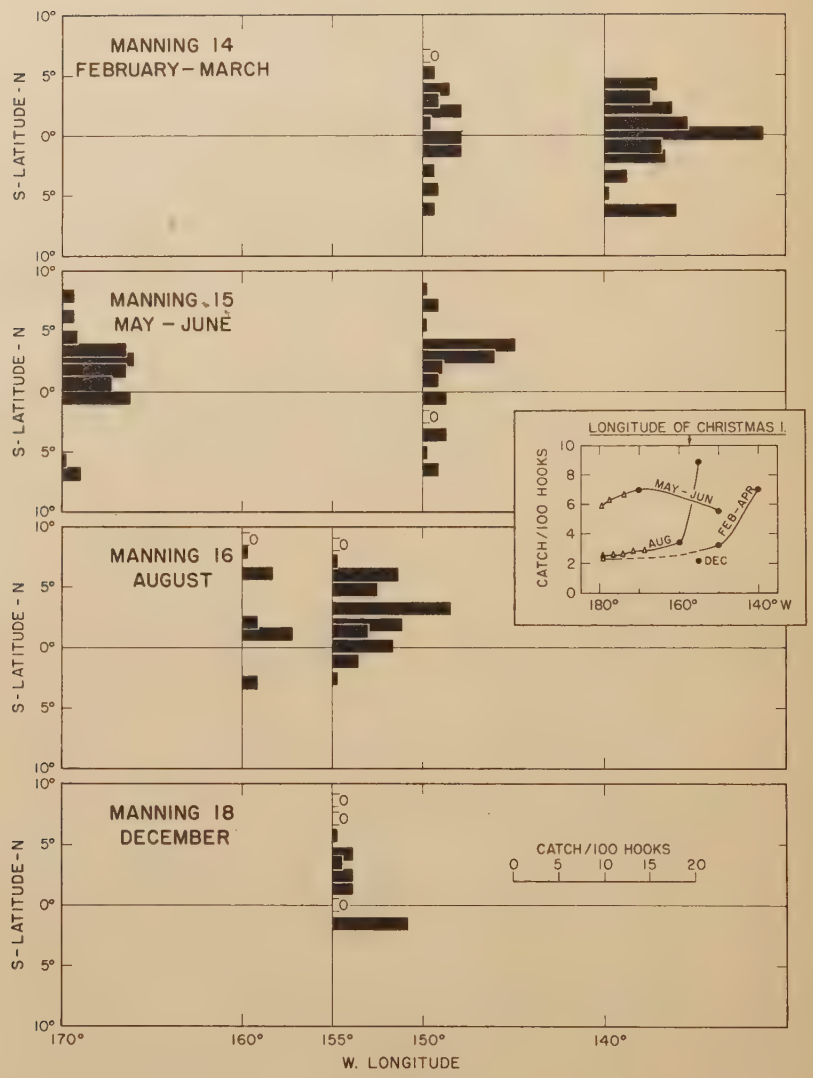

Figure 2.--Temporal and spatial distribution of long-line catches of yellowfin made during 1953 at stations more than 80 miles from land (data from appendix tables 6-11). Insert--diagrammatic representation of longitudinal variation in abundance (data from figs. 2 and 3). The round dots represent POFI data and the triangles represent Japanese data.

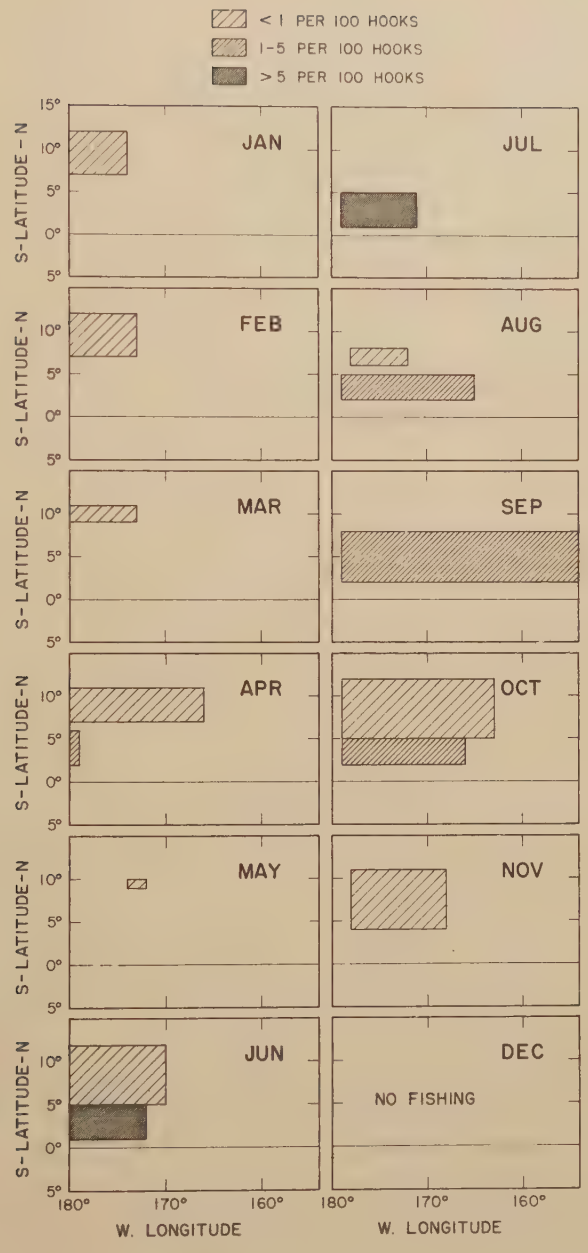

Figure 3.--Japanese commercial yellowfin catches in the central Pacific in 1953 (data from appendix table 12). The rectangles indicate the areas fished and the code indicates the catch rates.

Considering the distribution in relation to latitude, it is evide from figure 2 that during February and March the zone of highest yellowfin abundance straddled the Equator. During the period of May August the center of abundance lay about 2 degrees north of the Equat (fig. 2). In December there appears to have been a small concentrat centered north of the Equator (except for the high catch at a single st tion south of the Equator). Thus we see that during most times of the year the center of abundance of yellowfin was at or a little north of th Equator. The Japanese commercial fishing results (fig. 3) tend to co firm this conclusion in that they show yellowfin to have been more ab dant between the Equator and 5°N. than they were north of that latitud at all seasons in which any fishing was done in these latitudes. The Japanese catches do not lend themselves to more refined analysis because the data received by POFI were averaged by 5 degrees of latitude and there was no fishing south of the Equator.

The temporal changes along longitudes 150°W. and 155°W., th best sampled portions of our study area, are shown in figure 4. In th area the average yellow catch during February w small (2.4 per hundred hooks) at a time when go fishing was found farther to the east. Catches we higher during May (aver ing 5.5 per hundred hook but were smaller than th experienced further wes The highest average yell fin catch (7.3 per hundr hooks) of the year was attained during August, and during this same period poorer fishing wa found to the west. Fina during December fishing was again poor along 15 W. and 155°W. (1.6 per hundred hooks).

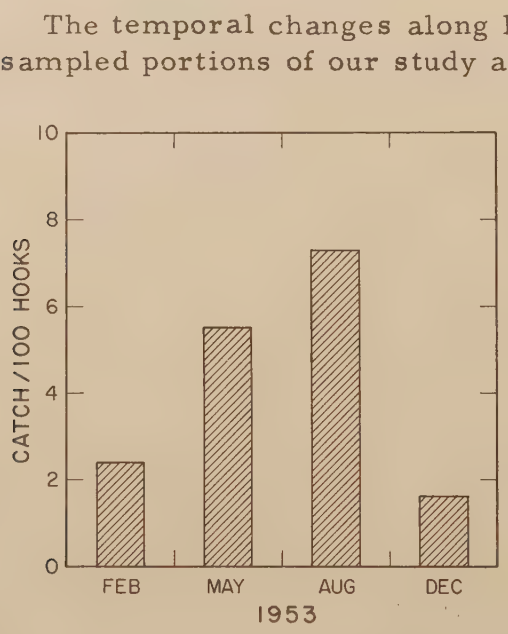

Figure 4.--Temporal variation of yellowfin abundance for stations between the Equator and 5°N. latitude at 150°-155°W. longitude (data from appendix tables 6-11).

Thus there is evidence that there were geographic shifts in the yellowfin population near the Equator with time, but these shifts cannc be precisely described on the basis of the information at hand. In

nmary, the pattern revealed by the available catch data suggests t yellowfin were centered over the Equator to the east of 150°W. ring February and March. Later in the year, during May and June, y were centered north of the Equator to the west of 150°W. During gust they were centered in the general vicinity of 150°W., and during cember they were scarce along 150°W. Whether these apparent fts in abundance are parts of a pattern of regularly recurring annual grations, or merely transient phenomena possibly associated with nges in the environment during one year is a problem that remains future study. Some indication that the shifts may be manifestations a stable pattern, as yet poorly understood, is given by the repeated currence of very good fishing along 150°-155°W. longitude during gust-September of 1951 and 1952 (Murphy and Shomura 1953a, 1955) l again in 1953.

Other Tunas

The distributions of the other three tunas (bigeye, albacore, and pjack) differ from that of the yellowfin and among each other. For tance, bigeye catches were sporadic and small in the vicinity of the uator, where yellowfin were most abundant (fig. 5). Generally big- e were most abundant north of 5°N. latitude, where yellowfin were arce. This is also shown in the results of Japanese fishing between 0°W. and 180° (appendix tables 12 and 13). It is worth noting that eye are nowhere as abundant as yellowfin, high catches ranging from o 5 per hundred hooks, whereas high yellowfin catches range from 5 15 per hundred hooks.

Albacore, unlike both bigeye and yellowfin, were most abundant uth of the Equator (fig. 5) with the peak catch at 6°S. on 170°W. This in general agreement with the results of earlier cruises, when they re found to be most abundant south of the Equator in the western port- n (170°W.-180°) of the survey area (Murphy and Shomura 1953b, 1955).

Skipjack were taken sporadically in small numbers throughout entire area, usually not more than one or two at a station (appendix les 6 to 11). These catches can hardly be taken as more than an indi- ion of the presence or absence of skipjack, for longlines do not sample s small, surface-schooling species effectively.

Relation of Catches to the Environment

The 1953 longline surveys substantiate earlier findings (Murphy l Shomura 1953a, b, 1955) on the relation of the distribution of deep- imming tunas to major features of the environment. In general

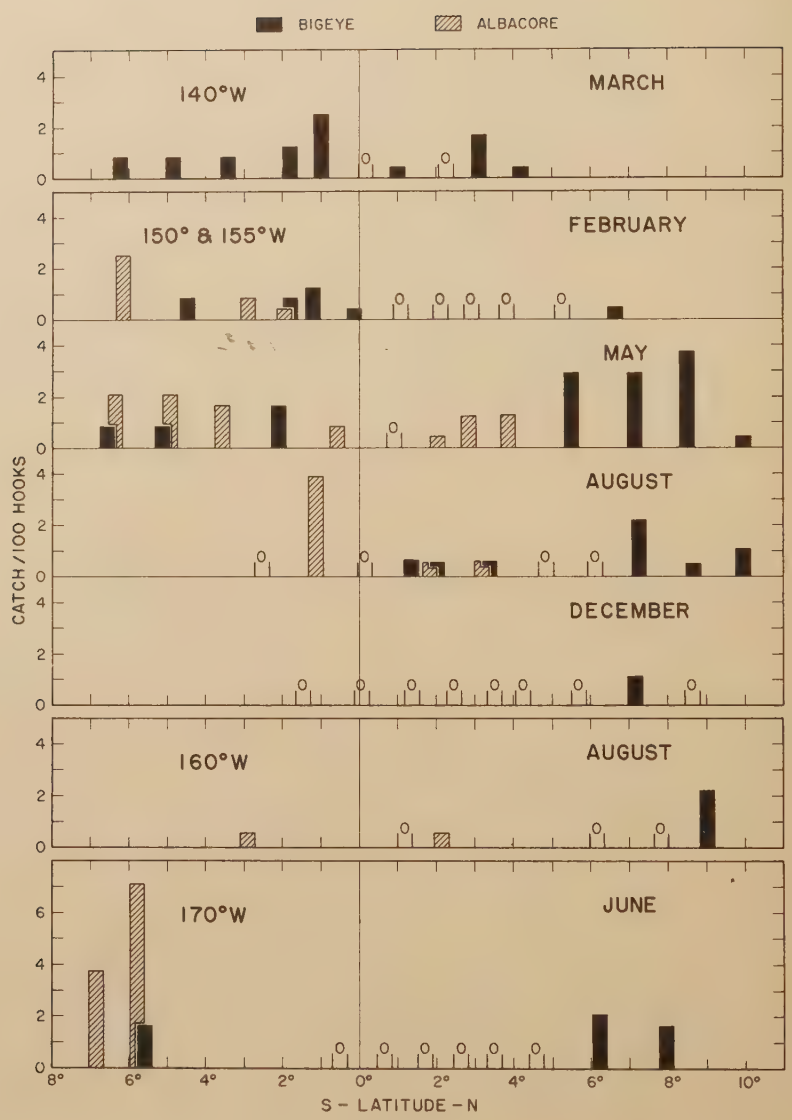

Figure 5.--Temporal and spatial distribution of longline catches of bigeye and albacore in 1953 at stations more than 80 miles from land (data from appendix tables 6-11).

owfin were most abundant near the Equator, where enrichment ough upwelling results in an augmented supply of plankton (King and nond 1953) presumably accompanied by an increase in tuna forage. s higher yellowfin abundance near the Equator, as compared with ions to the north and south, is clearly shown by the POFI surveys by Japanese tuna fishing. Bigeye were more abundant than yellow- north of the Equator, in the Countercurrent (roughly 5°N.-10°N. tude), although the population of bigeye there is not nearly as dense hat of the yellowfin to the south. At the present time the higher hes of albacore south of the Equator and west of 150°W. longitude not be associated with any particular feature of the environment.

The temperature sections drawn from bathythermograms taken ach fishing line are shown in figures 13 to 19 (appendix). Each ion, except those of Manning cruise 15 (figs. 15 and 16), shows characteristic features that appear to be associated with the tuna ulations. The isotherms sloping downward from about 10° to 5°N. ude roughly coincide with the easterly flowing Countercurrent, re bigeye are more abundant than yellowfin. South of 5°N. latitude he westerly flowing South Equatorial Current, where yellowfin are t abundant. Centered approximately at the Equator are the doming herms and lower surface temperatures associated with equatorial elling. Yellowfin are generally most abundant between the doming the Countercurrent.

However, during May and June of 1953 the characteristic ures of the current system were virtually absent (figs. 15 and 16) ng 150°W. and 170°W. longitude. Instead of the well defined slope ally associated with the Countercurrent, the slope was almost erceptible. The doming at the Equator was also very weak. For ance, the 80°F. isotherm did not reach the surface on 150°W., reas in all sections before and after this crossing the surface er at the Equator in this area has been cooler than 80°F. These ervations suggest a slowing down or stopping of the entire equatorial rent system, which was further indicated by the unusually slight t of the longline on the stations of Manning cruise 15. However, fishing results (fig. 2) show that this peculiar condition of the cir- tion did not affect the catches adversely; on the contrary, fishing ng 170°W. was better than in our previous experience (Murphy and mura 1953b) although it is entirely possible that these events in the ronment did affect the distribution of yellowfin at some later time.

Insular Catches

The tuna catches made at insular stations, i.e., those within 80 miles of land, during 1953 (table 2) were mostly yellowfin. These catches suggest that this species tends to be more abundant near land than in the open ocean, e.g., an average catch of 4.3 yellowfin per hundred hooks near Palmyra Island in late January 1953, while at approximately the same time (early February) catches in the open ocean at about the same latitude as Palmyra (5°-6°N.) averaged around 2 per hundred hooks.

Considerably more data are available in the instance of Christmas Island (2°N., 157°W.), where there was more fishing and where comparisons can be made between oceanic fishing (on 150°W. and 155°W. longitude) and insular fishing during several periods of the year (fig. 6). As shown in this figure, seasonal trends for the island fishing closely resembled seasonal trends for adjacent oceanic fishing, but in each instance the island catch was higher. For example, during August fishing was best at Christmas Island (10.9 per hundred hooks) and in the adjacent oceanic area (7.8 per hundred hooks). During January to February catches were low near Christmas Island (4.4 per hundred hooks) and only 2.4 per hundred hooks in the adjacent oceanic areas. As will be shown later, at least part of the higher catch near islands was caused by the addition of small fish to the catches of large deep-swimming yellowfin.

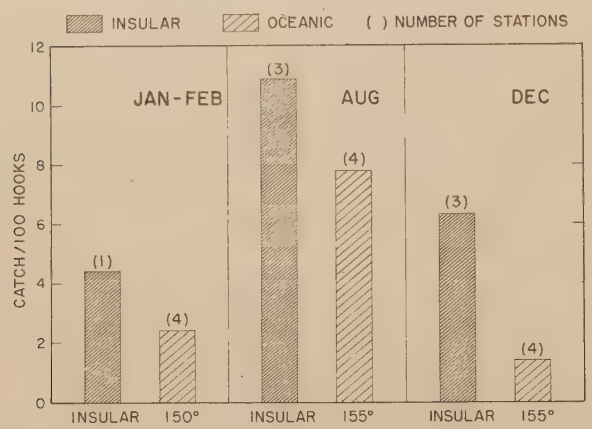

Figure 6.--Comparison of yellowfin catch rates from insular stations (within 80 miles of Christmas Island - 2°N. latitude, 157°W. longitude) and oceanic stations (at 150°-155°W. longitude between the Equator and 4°N. latitude). Data from appendix tables 6-11.

VERTICAL DISTRIBUTION OF TUNAS

In equatorial waters the tunas are not generally taken at the same rate at all depths fished by the longline (Nakamura 1949, Murphy and Shomura 1953a, b, 1955). Considering all of the 1953 data,

Table 2.--Yellowfin catch of insular fishing stations (within 80 miles of land). See appendix, tables 6 to 11, for more complete catch records

Cruise	Station	Yellowfin catch per hundred hooks	Distance from land	Approximate station position[1/]
			miles	
Smith 19	53	12.1	13	SW of Palmyra I.
(January-	56	2.9	5	S of Palmyra I.
February)	58	2.1	8	E of Palmyra I.
	60	0.0	40	E of Palmyra I.
	62	1.2	22	E of Christmas I.
	63	7.5	8	W of Christmas I.
	68	4.6	12	SW of Fanning I.
Manning 14	22	0.4	65	SW of Matahiva I.
(February-	24	2.9	70	NW of Ahe I.
March)				(Tuamotu Archipelago)
Manning 15	19	6.2	60	E of Sydney I.
(May-June)	20	0.8	30	NE of Phoenix I.
	21	2.1	80	NE of Enderbury I.
				(Phoenix Islands)
Manning 16	12	6.1	60	E of Christmas I.
(August)	13	16.1	17	NE of Christmas I.
	14	10.6	10	NW of Christmas I.
	20	2.8	30	SW of Malden I.
	22	9.4	65	S of Jarvis I.
	23	3.3	25	N of Jarvis I.
	26	1.1	70	SW of Fanning I.
	27	4.4	22	E of Washington I.
Manning 17	2	7.2	44	NE of Christmas I.
(October-	3	5.6	15	NE of Christmas I.
November)	4	10.3	21	NNW of Christmas I.
	5	12.5	42	NNW of Christmas I.
	6	7.0	46	S of Christmas I.
	7	11.4	20	S of Christmas I.
Manning 18	2	3.3	30	S of Malden I.
(December)	5	2.2	60	N of Malden I.
	16	2.8	63	E of Christmas I.
	18	13.3	20	NE of Christmas I.
	19	2.8	45	W of Christmas I.

[1/] Islands otherwise unspecified are in the Line Islands group

yellowfin were taken in somewhat greater numbers on the deeper hooks while albacore and bigeye were taken in markedly greater numbers on the deeper hooks.

As we were not able to determine reliably the absolute depth of the line during 1953, the distribution of the catches must be considered in terms of relative depth (see Murphy and Shomura 1955 for a summary of the measurements of absolute depth). We have separated the catches by relative depth by dividing the line into three levels, each occupied by two hooks that fish at the same level if the sag of the line forms a symmetrical curve. The records for the individual cruises in 1953 show that yellowfin were usually, but not always, taken in greater numbers on the deepest or on the two deeper levels (table 3). The catch of bigeye and albacore was always poor on the shallowest hooks, and usually best on the deepest hooks (table 3).

The difference in catch with depth is probably the result of at least three factors. In the Pacific, albacore and bigeye are taken in substantial numbers farther north and in cooler water than yellowfin and thus in the tropics these two species might be expected to be taken in greater numbers on hooks fishing the deeper, cooler strata. Secondly, King and Ikehara (MS) found slightly more food in the stomachs of yellowfin and bigeye taken on deeper hooks, suggesting that food is more available in the deeper levels fished by the gear. A complication is the tendency for more baits to remain on the deeper hooks through the fishing period (Shomura 1955). This latter cannot be the only cause of increased catch with depth, however, for the difference in bait retention is not as great as the difference in catch, and differences in bait effectiveness with depth can hardly explain the variation in catch with depth among the three species. The conclusion is that temperature preference and abundance of food are probably the most important factors associated with variation in the vertical distribution of deep-swimming tunas in the equatorial Pacific.

SIZE COMPOSITION OF THE CATCHES OF TUNA

Yellowfin

The size composition of longline-caught yellowfin is in part a function of the nearness of land. This is shown when the 1953 catches are grouped into those made within 80 miles of land and those made farther from land (fig. 7). This separation, the same as that made when considering abundance in an earlier section, clearly points up

Table 3.--Tuna catch by relative hook depth, 1953 (data from standard 6-hook gear only)

Cruise	Shallow hooks (hooks 1 and 6)	Intermediate hooks (hooks 2 and 5)	Deep hooks (hooks 3 and 4)
Yellowfin			
Manning 14	74	80	73
Smith 19	38	36	42
Manning 15	47	68	79
Manning 16	40	82	80
Manning 17	18	21	30
Manning 18	11	23	40
Total	228	310	344
Bigeye			
Manning 14	5	12	14
Smith 19	1	-	-
Manning 15	4	18	23
Manning 16	5	3	9
Manning 17	-	-	3
Manning 18	-	-	3
Total	15	33	52
Albacore			
Manning 14	-	9	22
Smith 19	-	-	-
Manning 15	7	28	28
Manning 16	2	3	12
Manning 17	1	2	1
Manning 18	-	-	1
Total	10	42	64
Skipjack			
Manning 14	6	7	8
Smith 19	-	-	-
Manning 15	6	4	5
Manning 16	2	-	4
Manning 17	1	-	-
Manning 18	1	2	-
Total	16	13	17

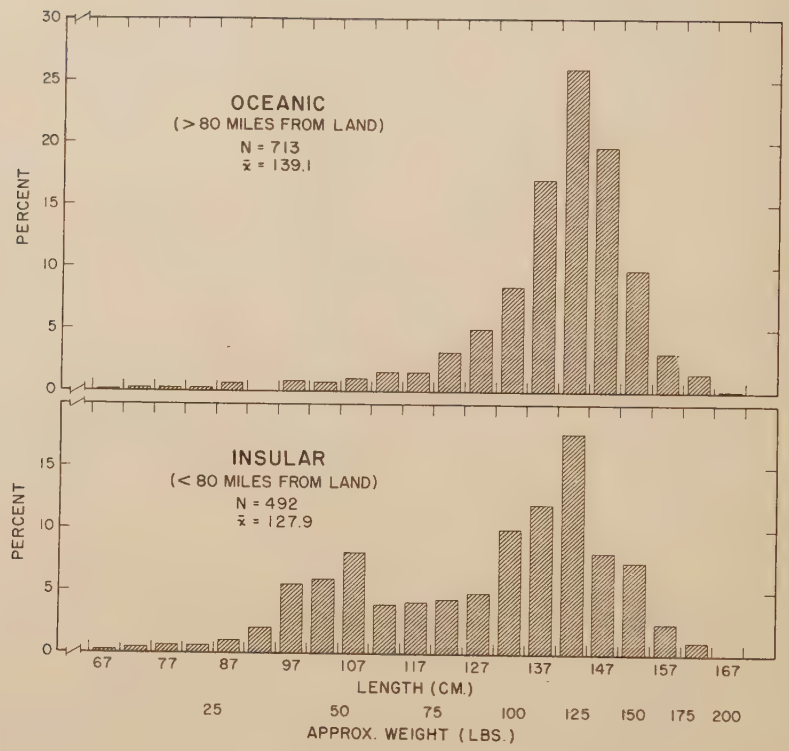

Figure 7.--Yellowfin size distribution with distance from land (data in appendix table 14).

the greater number of small fish (around 100 cm. = 43 lbs.) near land, while the major mode of large fish is at 142 cm. (123 lbs.) in both instances.

If the 1953 catches are arranged by longitude of capture (fig. 8), the size composition is virtually the same for 140°W., 150°W., and 160°W. (modes at 142 cm. = 123 lbs.), excepting that a few more small fish were captured to the west. Contrasting with this uniformity is the sample from 170°W., where the major mode is some 5 cm. less (137 cm. = 110 lbs.) (fig. 8).

Yellowfin captured on 150°-155°W., when arranged by time of year (fig. 9), show that the size composition did not change materially through 1953, except for the appearance of more small fish in the catch made during the last half of the year. Even this change may merely reflect distance from land, for the latter two samples are from 155°W., 300 miles closer than 150°W. longitude to the Line Islands, where small yellowfin are comparatively abundant.

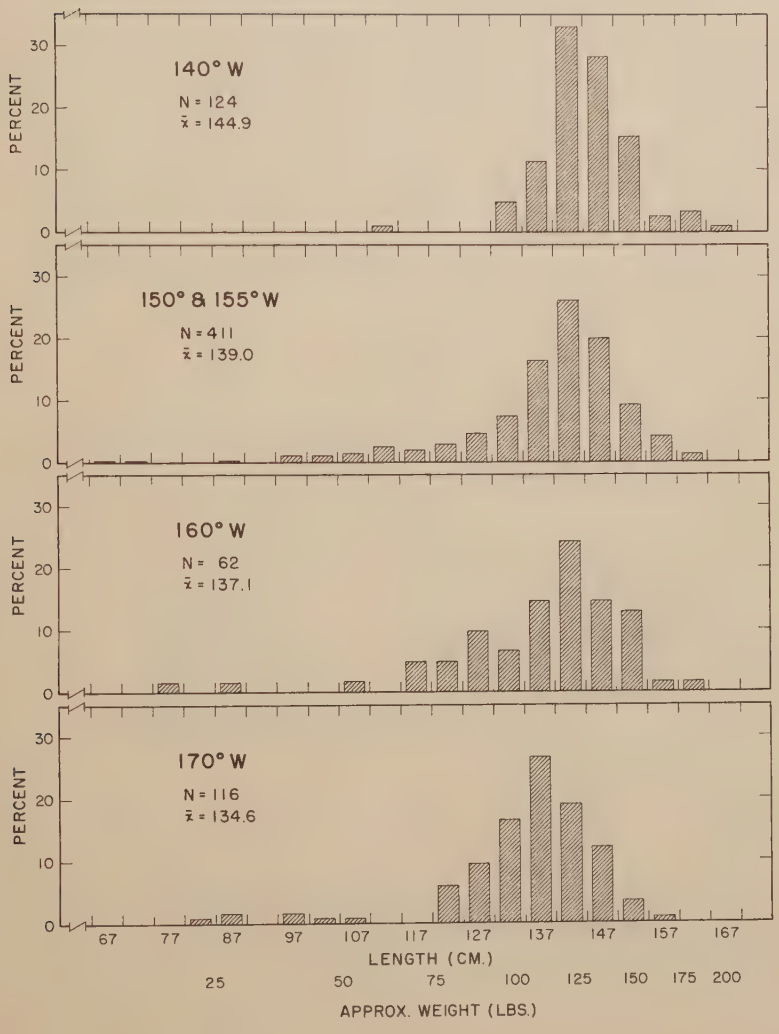

Figure 8.--Yellowfin size distribution by longitude (data in appendix table 14).

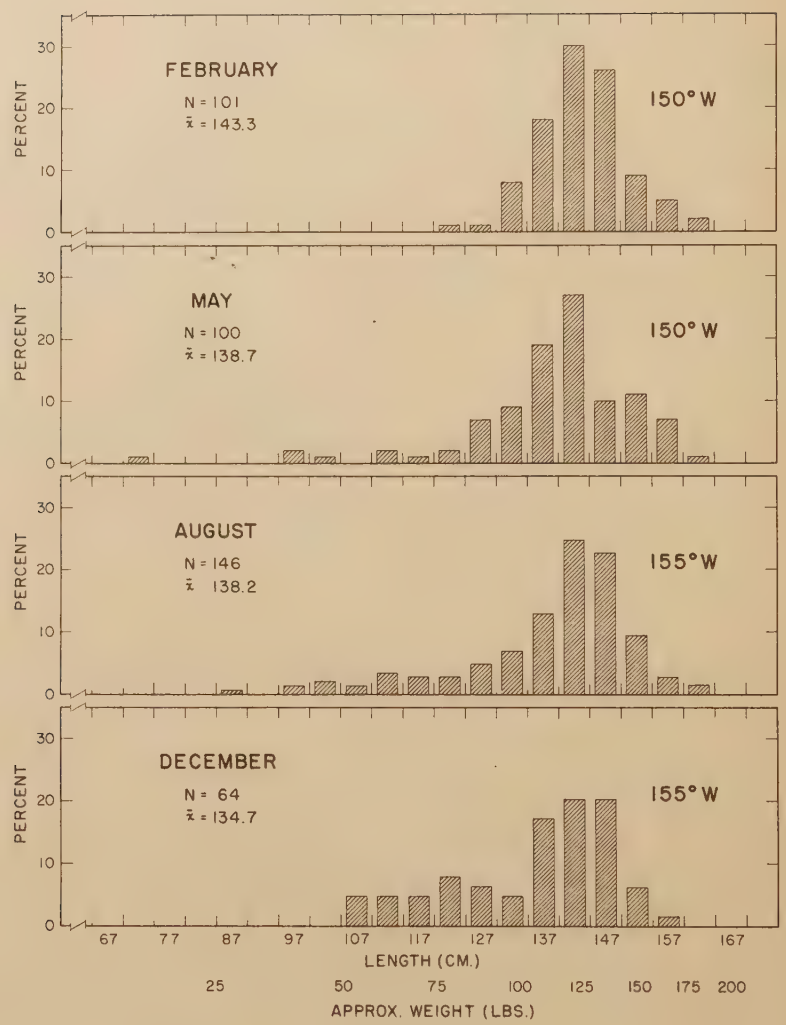

Figure 9.--Yellowfin size distribution by time of year at 150°-155°W. longitude (data in appendix table 14).

Other Tunas

The numbers of bigeye, albacore, and skipjack taken during 1953 re too small to warrant detailed analysis. As a whole (fig. 10) they re similar in size to our past catches on the longline in the equatorial ntral Pacific. About 90 percent of the bigeye were 122-172 cm. in ngth (85-232 lbs.), of the albacore 91-103 cm. (36-51 lbs.), and of e skipjack 70-81 cm. (18-29 lbs.).

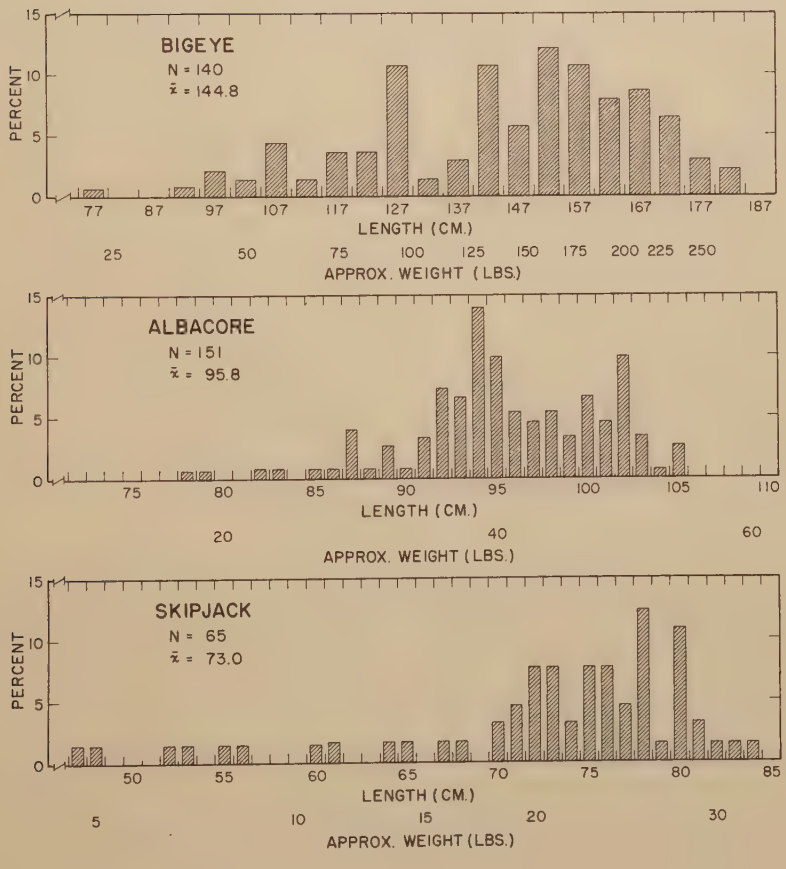

Figure 10.--Size distribution of other tunas (data in appendix table 15).

SEX COMPOSITION OF THE TUNA CATCHES

There was a preponderance of males among the yellowfin taken during 1953. As in past samples (Murphy and Shomura 1955), the sexes were about equally represented in the 1953 yellowfin catches up to 137 cm. (110 lbs.), and above this size males clearly predominated (fig. 11).

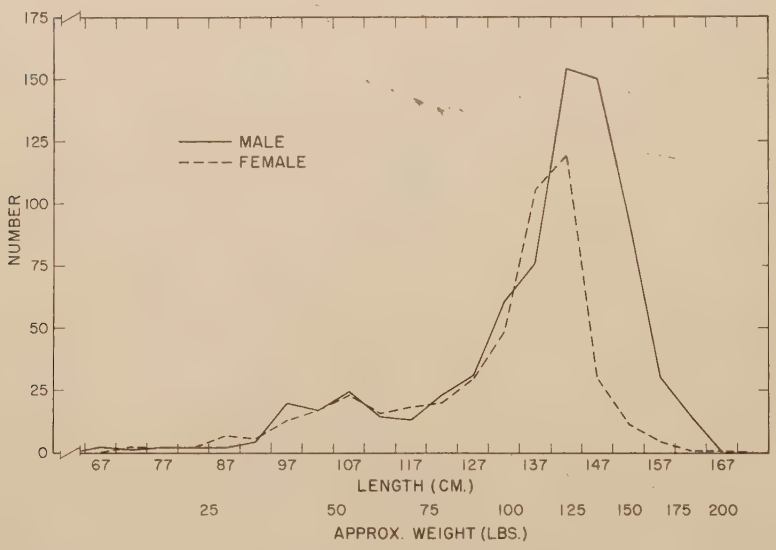

Figure 11.--Yellowfin size distribution by sex, 1953 (data in appendix table 15).

The bigeye (fig. 12) also showed an unbalanced sex ratio but the 1953 samples include too few fish to yield a satisfactory description. There is a tendency, however, for males to dominate among fish larger than 122 cm. (85 lbs.). Among the larger albacore, males definitely dominate (fig. 12), but again the samples are too small to describe the sex ratio adequately at all sizes. Of the 66 skipjack taken in 1953, 30 were females, and there was about even representation throughout the lengths captured (47-85 cm. = 5-34 lbs.).

CHANGES IN LONGLINE GEAR

Three basic innovations were made to the longline gear during 1953 (Mann MS). The first was shortening the droppers in order to reduce construction costs and handling labor. The second was the insertion in the mainline of a wire link to which the dropper is snapped, an improvement designed to reduce the number of tangles. Finally, an attempt was made to discover the optimum hook spacing along the main line. These changes are interrelated and their development was to some extent simultaneous, but for the sake of clarity we will consider each separately.

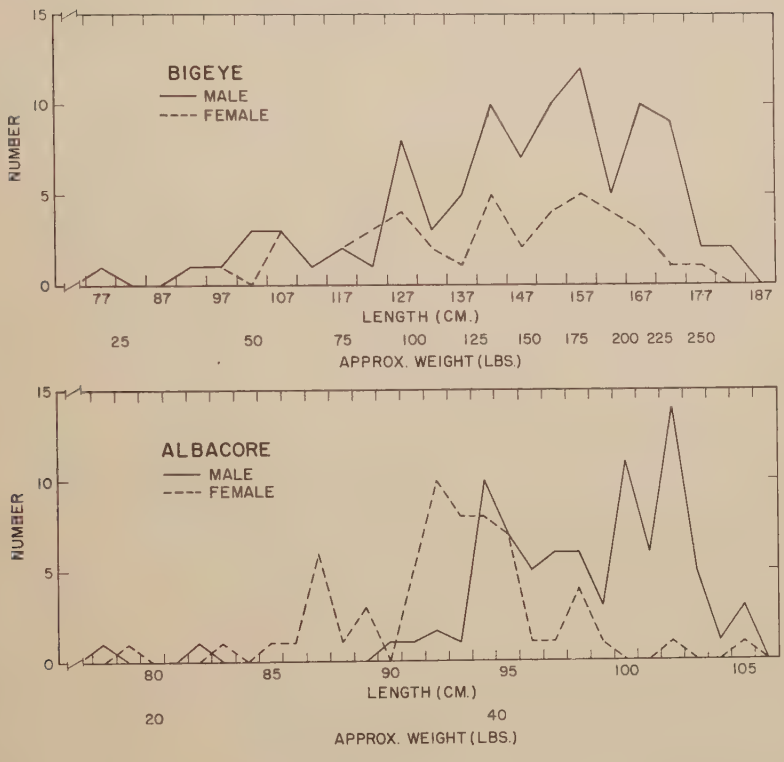

Figure 12.--Bigeye and albacore size distribution by sex, 1953 (data in appendix table 15).

Improvements in Construction

Experience with longline gear equipped with six 11-fathom droprs (10 fathoms of cotton and 1 fathom of leader) per basket suggested at much labor during hauling and considerable fabrication expense uld be saved if the droppers could be shortened without reducing the tch. Accordingly, droppers consisting of 1 fathom of 261-thread cotn line and 1 fathom of leader were tested on two cruises.

During the first experiment 20 baskets of short-dropper gear re fished at each of 12 stations. The total catch on this gear was

88 fish including all species, and 82 fish were taken on the adjacent 20 baskets of long-dropper gear. During the second experiment 10 baskets of short-dropper gear were fished on each of six stations. The total catch was 46 on the special gear and 34 on the regular gear. Although the design of these experiments did not provide perfect statistical control of soaking time, the results suggested that short droppers were as efficient as long ones as far as catching fish is concerned.

Shortening the droppers did not actually reduce the labor during the hauling, however, for the short droppers tended to tangle (wrap around the mainline) more than the long droppers. This is reflected in the average hauling time of 4.0 minutes for short-dropper gear compared to 3.6 minutes for baskets equipped with long droppers fished at the same time.

Excessive tangling of short droppers was virtually eliminated by introducing a wire link in the mainline. Each dropper is snapped on this link or bridle, which turns freely in the AK snap, and thus the dropper is rarely wrapped on the mainline when the latter twists, as it frequently does when under tension. This was shown quantitatively during three cruises when wire bridles were used. Of 1,181 baskets with 11 short droppers (2 fathoms of cotton and 1 fathom of leader) and wire links, 86 percent had one or no tangle, while of 1,433 baskets with 6 long droppers and no links only 63 percent had one or no tangle. Reduced tangling is also reflected in the hauling time, for 11-hook gear with wire links was hauled in an average of 3.7 minutes per basket over the three cruises, while the regular 6-hook gear (fished at the same stations) averaged 3.9 minutes per basket (excluding baskets with broken mainlines).

Changes in Hook Spacing

Changes in hook spacing along the mainline were initiated in 195 in order (1) to ascertain the most efficient hook spacing from operationa (i.e., commercial) aspects, and (2) to provide additional information on the schooling behavior of the fish. Analysis of the catches of 6-hook gear (Murphy and Elliott 1954) suggested that yellowfin were schooled, and if this were true, the catch over a given unit of line should be greater if more hooks are available to the schools of fish that encounter a segment of line. These experiments are continuing, so this discussion must be considered a preliminary report.

In each of the experiments described below, standard gear with ooks, 30 fathoms apart, on a 210-fathom mainline was used as a trol. The 11-hook experimental gear differed from the standard r in having an extra hook between each of the original hooks and in ing all short droppers (3 fathoms overall) which were attached to e bridles in the mainline. These innovations made interpretation of hook spacing results a little complex and imprecise, but time was available to test each variable in turn.

The first experiment involving closer hook spacing was primarily est of (1) the wire links discussed above, and (2) the practicability spacing droppers closer together. During the test, 10 baskets of perimental gear with 11 hooks, 15 fathoms apart, were appended to end of sets of 40 baskets of standard gear with 6 hooks, 30 fathoms art, at each of 26 stations (Manning cruise 15). The 11-hook gear rformed satisfactorily from a mechanical point of view and took 73 llowfin. This compares very favorably (1.43x) with the catch of 51 llowfin on the adjacent 10 baskets of 6-hook gear. The 11-hook gear s on the end of the set, however, and fished about 10 percent longer an the adjacent 6-hook gear, which may have accounted for a portion the larger catch.

The catch rates on 11- and 6-hook gear from subsequent experi-ents may be compared directly because fishing time was controlled alternating the gear along the entire set. Usually the 6- and 11-hook skets were alternated in groups of five. A summary of the results of ree experiments is shown in table 4. During these cruises the 11-ok gear took 1.21x the catch of the 6-hook gear, something less than e hook ratio 11/6 (1.83x).

Table 4.--Comparison of the catches of 6- and 11-hook gear

Cruise	Number of stations	6-hook		11-hook	
		Number of baskets	Yellow-fin	Number of baskets	Yellow-fin
Manning 16	26	775	202	507	162
Manning 17	6	139	72	139	76
Manning 18	14	420	76	420	99
Total	46	1334	350	1066	337
Number per basket			0.262		0.316

An operational trial of 21-hook gear (branch lines 7.5 fathoms apart) was conducted at 18 stations on Manning cruise 16. This experiment consisted of appending 10 baskets of 21-hook gear to the longest fishing end of sets of mixed 6- and 11-hook gear. The results at two stations were complicated by the presence of land, and on four stations no yellowfin were taken. On the remaining 12 stations the 21-hook gear caught 71 yellowfin, the nearest 8 baskets of 11-hook gear caught 21 yellowfin, and the nearest 12 baskets of 6-hook gear took 53 yellowfin. The respective catches per basket were 0.68 for 21-hook, 0.22 for 11-hook, and 0.37 for 6-hook. These data suggest that the catch per basket can be increased over that given by the 11-hook gear, but it is also evident that sampling was inadequate and that fishing time was not equal, for the 21-hook gear was in the water longest.

Spacing the hooks closer together, at intervals of about 15 fathoms, appears to be advantageous to commercial fishermen. The additional cost of adding 5 droppers to the normal 6-hook gear is so small that a decision would appear to hinge on the speed of hauling. Experimental data are not available, but the increase in hauling time due to extra hooks can be inferred from time studies on the 11-hook gear.

In the absence of tangles one basket of 11-hook gear is hauled in about $3^{m}\ 00^{s}$. On the average about 3 seconds is required to remove a dropper (time from stop to start of the hauler). Extrapolating we estimate that 6-hook gear with wire links would have been hauled in $2^{m}\ 45^{s}$. The 11-hook gear then takes 1.09 times as long to haul, and our information to date indicates that it catches 1.21 times as many yellowfin.

Another factor to be considered, however, is the tendency for more branch lines to break or be lost when using the 11-hook gear with the wire sections. For instance 559 baskets of 6-hook gear (3,354 branch lines) suffered 25 broken branch lines. At the same time 559 baskets of 11-hook gear (6,149 branch lines) suffered 66 broken branch lines. The percent of failure is 0.75 in the 6-hook gear and 1.01 in 11-hook gear, indicating that design changes that reduce branch line failures will further increase the catch of 11-hook gear relative to that of the 6-hook gear.

In summary, it appears that the Japanese-type gear on which POFI based its 6-hook baskets has been substantially improved by innovations in construction and by spacing hooks closer together.

bandoning the sekiyama (Murphy and Shomura 1955, Mann MS) and
ortening droppers reduced the cost of fabrication. Introducing the
ire mainline section reduced tangling and therefore the amount of
bor during hauling. Spacing branch lines 15 fathoms apart instead of
0 fathoms increased the catch more than it increased the labor. It is
qually clear that many development problems remain, e.g., reducing
e incidence of dropper failure and determining the optimum hook
pacing.

SHARK DAMAGE TO TUNA CATCHES

During the period the longline is in the water (5 to 10 hours) a
ortion of the tuna catch is damaged by sharks. This damage, sum-
arized in table 5, suggests that commercial operators can expect
o lose about 20 percent of their catches when fishing in the central
quatorial Pacific.

Table 5.--Summary of shark-bitten tuna, 1953 (includes catches made on all types of gear and excludes results of special stations)

Cruise	Yellowfin		Bigeye		Albacore		Skipjack		Grand total	
	Total catch	Percent shark-bitten	Total catch	Percent shark-bitten	Total catch	Percent shark-bitten	Total catch	Percent shark-bitten	Total catch	Percent shark-bitten
Manning 14	276	20.7	34	14.7	39	0.0	28	7.1	377	17.0
Smith 19	127	33.9	1	0.0	-	-	1	0.0	129	33.3
Manning 15	270	10.7	57	12.3	98	14.3	22	13.6	447	11.9
Manning 16	466	22.5	51	11.8	31	19.4	15	6.7	563	21.0
Manning 17	149	16.1	6	16.7	4	25.0	4	0.0	163	16.0
Manning 18	171	22.8	8	25.0	2	50.0	6	16.7	187	23.0
Total	1459	20.4	157	13.4	174	12.6	76	9.2	1871 1/	18.8

1/ Includes 5 unidentified, badly shark-bitten tunas

SUMMARY

. The Pacific Oceanic Fishery Investigations conducted six longline cruises in the equatorial region of the Pacific between 140°W. and 170°W. longitude during 1953.

. The catches experienced during the several crossings of the equatorial current system were consistent with earlier findings. Yellowfin were found most abundant in the region near the Equator which is enriched by upwelling. Bigeye were most abundant in the region of the Countercurrent, and albacore most abundant south of the Equator.

. The results suggest that the longitude of best catch shifted during the year, and that east-west movements recur from year to year.

. Catches around Christmas Island were higher than in the open ocean, at least in part because small "surface yellowfin" were taken in addition to the large deep-swimming yellowfin.

. Yellowfin were usually taken in greater numbers on the deeper hooks of the longline. Bigeye and albacore catches exhibited this tendency more markedly than those of yellowfin.

. During 1953 more small yellowfin were taken near islands than offshore. The size of oceanic yellowfin was uniform from 140°W. to 160°W. longitude, but specimens from 170°W. were smaller. The size of the yellowfin taken at 150°-155°W. longitude did not change materially throughout the year.

7. Males predominated among the larger yellowfin, bigeye, and albacore.

8. Short droppers (2-3 fathoms) appeared to be as efficient as long branch lines (10 fathoms), except for a tendency to break more often.

9. The use of wire links in the mainline, to which branch lines are attached, materially reduced the number of tangles.

0. Increasing the number of branch lines on 1,260 feet of mainline from 6 to 11 increased the catch about 21 percent. This increase was greater than the additional hauling time imposed by the added branch lines.

1. Shark damage to the tuna catch averaged 18.8 percent.

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APPENDIX

Table 6.--Manning cruise 14, summary of the tuna catch on 6-hook gear (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack)

Station	Date	Noon position		Number of hooks	Catch per 100 hooks				
		Latitude	Longitude		YF	BE	Alb.	SJ	Total
1	1-23-53	20°52'N.	157°18'W.	234	-	-	-	-	-
2	1-26-53	15°46'N.	154°13'W.	240	-	0.42	-	-	0.42
3	1-28-53	12°20'N.	151°47'W.	240	-	-	-	-	-
4	1-31-53	06°38'N.	150°12'W.	228	-	0.44	-	-	0.44
5	2-1-53	05°15'N.	149°55'W.	240	1.25	-	-	0.42	1.67
6	2-2-53	03°49'N.	150°07'W.	240	2.92	-	-	-	2.92
7	2-3-53	02°54'N.	150°25'W.	240	1.67	-	-	0.83	2.50
8	2-4-53	02°06'N.	150°09'W.	234	4.27	-	-	0.43	4.70
10	2-10-53	01°04'N.	151°05'W.	240	0.83	-	-	-	0.83
11	2-11-53	00°09'S.	150°03'W.	240	4.17	0.42	-	1.25	5.83
12	2-12-53	01°13'S.	150°11'W.	240	4.17	1.25	-	-	5.83[2]
17	2-16-53	01°55'S.	150°07'W.	240	-	0.83	0.42	0.83	2.08
18	2-17-53	02°56'S.	150°12'W.	240	1.25	-	0.83	-	2.08
19	2-18-53	04°29'S.	150°16'W.	240	1.67	0.83	-	-	2.50
20	2-19-53	06°08'S.	150°09'W.	240	1.25	-	2.50	0.42	4.17
21	2-21-53	11°27'S.	149°47'W.	240	1.25	-	1.25	-	2.50
22	2-23-53	15°32'S.	149°34'W.	240	0.42	-	1.25	-	1.67
24	3-4-53	13°31'S.	147°08'W.	240	2.92	-	2.08	-	5.42[2]
25	3-6-53	10°09'S.	144°31'W.	240	0.83	0.42	4.58	-	5.83
26	3-8-53	06°16'S.	141°32'W.	240	7.92	0.83	-	-	8.75
27	3-9-53	04°52'S.	140°36'W.	240	0.42	0.83	-	1.67	2.92
28	3-10-53	03°25'S.	140°03'W.	240	2.50	0.83	-	0.42	3.75
29	3-11-53	01°48'S.	139°59'W.	240	6.67	1.25	-	-	7.92
32	3-13-53	01°00'S.	140°05'W.	240	6.25	2.50	-	-	8.75
33	3-14-53	00°09'N.	139°47'W.	240	17.50	-	-	0.83	18.33
34	3-15-53	01°00'N.	140°00'W.	240	9.17	0.42	-	0.42	10.00
35	3-16-53	02°14'N.	140°18'W.	240	7.50	-	-	-	7.50
36	3-17-53	03°07'N.	140°07'W.	240	5.00	1.67	-	0.83	7.50
37	3-18-53	04°12'N.	140°20'W.	240	5.83	0.42	-	0.42	6.67

[1] Calculated independently

[2] Includes one unidentified, shark-bitten tuna

Table 7.--Smith cruise 19, summary of the tuna catch on 6-hook gear

ion	Date	Noon position		Number of hooks	Catch per 100 hooks		
		Latitude	Longitude		Yellowfin	Bigeye	Total[1/]
3	1-23-53	05°49'N.	162°22'W.	240	12.08	-	12.08
5	1-25-53	05°48'N.	162°07'W.	240	2.92	-	2.92
3	1-26-53	05°54'N.	161°52'W.	240	2.08	-	2.08
0	1-27-53	05°54'N.	161°20'W.	240	-	-	-
2	1-31-53	01°44'N.	156°47'W.	240	1.25	-	1.25
3	2-1-53	01°50'N.	157°40'W.	240	7.50	-	7.50
8	2-5-53	03°46'N.	159°33'W.	240	4.58	0.42	5.00

[1/] Calculated independently

Table 8.--Manning cruise 15, summary of the tuna catch on 6-hook gear
(YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack)

Station	Date	Noon position		Number of hooks	Catch per 100 hooks				
		Latitude	Longitude		YF	BE	Alb.	SJ	Total
1	4-29-53	19°38'N.	156°15'W.	240	-	-	-	-	-
2	5-3-53	09°57'N.	151°07'W.	240	-	0.42	-	-	0.42
3	5-4-53	08°31'N.	150°17'W.	240	0.42	3.75	-	-	4.17
5	5-5-53	07°08'N.	150°06'W.	240	1.67	2.92	-	-	4.58
6	5-6-53	05°30'N.	150°00'W.	240	0.42	2.92	-	-	3.33
7	5-7-53	03°52'N.	150°05'W.	234	10.26	-	1.28	1.28	12.82
8	5-8-53	02°50'N.	150°04'W.	240	7.92	-	1.25	0.42	9.58
10	5-10-53	02°02'N.	149°55'W.	240	2.08	-	0.42	0.42	2.92
11	5-11-53	00°54'N.	149°46'W.	240	1.67	-	-	-	1.67
12	5-12-53	00°36'S.	150°07'W.	240	2.50	-	0.83	0.42	3.75
13	5-13-53	02°06'S.	150°06'W.	240	-	1.67	-	0.83	2.50
14	5-14-53	03°35'S.	150°02'W.	240	2.50	-	1.67	-	4.17
15	5-15-53	05°03'S.	150°04'W.	240	0.42	0.83	2.08	-	3.33
16	5-16-53	06°28'S.	150°00'W.	240	1.67	0.83	2.08	0.42	5.00
17	5-28-53	06°51'S.	170°02'W.	240	2.08	-	3.75	-	5.83
18	5-29-53	05°41'S.	169°44'W.	240	0.42	1.67	7.08	0.83	10.00
19	5-30-53	04°26'S.	170°09'W.	240	6.25	-	2.08	-	8.33
20	5-31-53	03°27'S.	170°12'W.	246	0.81	0.41	2.85	-	4.06
21	6-1-53	02°14'S.	170°00'W.	240	2.08	-	0.83	0.42	3.33
22	6-2-53	00°30'S.	169°52'W.	240	7.50	-	-	0.42	7.92
23	6-3-53	00°38'N.	169°57'W.	240	5.42	-	-	-	5.42
24	6-4-53	01°43'N.	169°59'W.	240	7.08	-	-	-	7.08
25	6-5-53	02°38'N.	169°59'W.	240	7.92	-	-	0.42	8.33
26	6-6-53	03°30'N.	170°09'W.	240	7.08	-	-	-	7.08
27	6-7-53	04°34'N.	170°11'W.	240	1.67	-	-	-	1.67
28	6-8-53	06°13'N.	170°07'W.	240	1.25	2.08	-	0.42	3.75
29	6-9-53	07°57'N.	169°48'W.	240	1.25	1.67	-	-	2.92

1/ Calculated independently

Table 9.--Manning cruise 16, summary of the tuna catch on 6-hook gear (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack)

ion	Date	Noon position		Number of hooks	Catch per 100 hooks				
		Latitude	Longitude		YF	BE	Alb.	SJ	Total[1/]
1	7-25-53	20°47'N.	157°26'W.	174	-	-	-	-	-
2	7-29-53	09°57'N.	155°06'W.	186	-	1.08	-	-	1.08
4	7-30-53	08°39'N.	154°57'W.	192	-	0.52	-	-	0.52
6	7-31-53	07°15'N.	155°04'W.	180	0.56	2.22	-	0.56	3.33
8	8-1-53	06°06'N.	154°49'W.	180	7.22	-	-	-	7.22
9	8-2-53	04°49'N.	155°10'W.	180	5.00	-	-	0.56	5.55
10	8-3-53	03°15'N.	154°59'W.	168	13.10	0.60	0.60	-	14.29
11	8-4-53	01°55'N.	155°21'W.	180	7.78	0.56	0.56	-	8.89
12	8-5-53	02°06'N.	156°13'W.	180	6.11	1.11	0.56	-	7.78
13	8-6-53	02°09'N.	157°04'W.	174	16.09	-	0.56	-	16.67
14	8-7-53	02°05'N.	157°38'W.	180	10.56	-	-	-	10.56
16	8-12-53	01°21'N.	155°16'W.	156	3.85	0.64	-	-	4.49
17	8-13-53	00°08'N.	154°51'W.	180	6.67	-	-	0.56	7.22
18	8-14-53	01°08'S.	155°18'W.	180	2.78	-	3.89	-	6.67
19	8-15-53	02°33'S.	155°23'W.	180	0.56	-	-	-	0.56
20	8-16-53	04°10'S.	155°33'W.	180	2.78	-	0.56	-	3.33
21	8-18-53	02°56'S.	160°14'W.	180	1.67	-	0.56	-	2.22
22	8-19-53	01°31'S.	159°53'W.	180	9.44	0.56	1.67	-	11.67
23	8-20-53	00°01'S.	159°56'W.	180	3.33	-	-	0.56	3.89
24	8-21-53	01°11'N.	160°08'W.	180	5.56	-	-	-	5.56
25	8-22-53	02°08'N.	160°24'W.	180	1.67	-	0.56	-	2.22
26	8-23-53	03°22'N.	160°24'W.	180	1.11	-	-	-	1.11
27	8-24-53	04°43'N.	160°00'W.	180	4.44	-	-	-	4.44
28	8-25-53	06°10'N.	160°02'W.	180	3.33	-	-	0.56	3.89
29	8-26-53	07°50'N.	159°24'W.	180	0.56	-	-	-	0.56
30	8-27-53	09°00'N.	159°40'W.	180	-	2.22	-	0.56	2.78

[1/] Calculated independently

Table 10.--Manning cruise 17, summary of the tuna catch on 6-hook g
(YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack)

Station	Date	Noon position		Number of hooks	Catch per 100 hooks				
		Latitude	Longitude		YF	BE	Alb.	SJ	Tota
2	10-27-53	02°26'N.	156°42'W.	180	7.22	0.56	-	-	7.7
3	10-28-53	02°06'N.	157°04'W.	180	5.56	-	-	-	5.5
4	10-29-53	02°05'N.	157°50'W.	126	10.32	-	-	-	10.3
5	10-30-53	02°15'N.	158°09'W.	120	12.50	1.67	1.67	0.83	16.6
6	10-31-53	00°54'N.	157°26'W.	114	7.02	-	0.88	-	7.8
7	11-1-53	01°29'N.	157°36'W.	114	11.40	-	0.88	-	12.2

1/ Calculated independently

Table 11.--Manning cruise 18, summary of the tuna catch on 6-hook ge
(YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack)

Station	Date	Noon position		Number of hooks	Catch per 100 hooks				
		Latitude	Longitude		YF	BE	Alb.	SJ	Tota
2	12-1-53	04°33'S.	155°08'W.	180	3.33	-	0.56	-	3.8
5	12-2-53	03°02'S.	155°12'W.	180	2.22	0.56	-	-	2.7
8	12-3-53	01°28'S.	155°28'W.	180	8.33	-	-	-	8.3
10	12-4-53	00°03'N.	155°15'W.	180	-	-	-	-	-
12	12-5-53	01°22'N.	155°18'W.	180	2.22	-	-	0.56	2.7
14	12-6-53	02°27'N.	155°26'W.	180	2.22	-	-	-	2.2
16	12-7-53	01°59'N.	156°09'W.	180	2.78	-	-	0.56	3.3
18	12-8-53	02°14'N.	157°08'W.	180	13.33	-	-	-	13.3
19	12-9-53	02°01'N.	158°15'W.	180	2.78	-	-	-	2.7
21	12-11-53	03°31'N.	155°23'W.	180	1.11	-	-	-	1.1
23	12-12-53	04°14'N.	154°56'W.	180	2.22	-	-	-	2.2
25	12-13-53	05°42'N.	154°57'W.	180	0.56	-	-	-	0.5
27	12-14-53	07°09'N.	155°00'W.	180	-	1.11	-	0.56	1.6
29	12-15-53	08°38'N.	155°04'W.	180	-	-	-	-	-

1/ Calculated independently

Table 12.--Results of Japanese commercial tuna fishing in the central Pacific during 1953 (data from Nomura et al. 1953)

Month	Latitude	Longitude	Number of hooks	Average catch per 100 hooks						
				Yellow-fin	Big-eye	Alba-core	Skip-jack	Spear-fish 1/	Sharks	Misc.
Jan.	7°-12°N.	180°-174°W.	384,515	0.41	2.67	0.11	0.04	0.39	0.47	-
Feb.	7°-12°N.	180°-173°W.	265,365	0.31	2.51	0.08	0.03	0.30	0.52	0.04
March	9°-11°N.	180°-173°W.	196,360	0.65	2.03	0.08	0.08	0.44	0.44	0.15
April	7°-11°N.	180°-166°W.	226,221	0.48	2.02	0.02	0.05	0.55	0.17	-
	2°-6°N.	180°-179°W.	38,500	2.75	0.62	-	-	0.78	-	-
May	9°-10°N.	174°-172°W.	24,500	0.38	2.74	0.01	0.17	0.68	1.07	-
June	5°-12°N.	180°-170°W.	95,135	0.63	2.36	0.05	0.12	0.64	0.04	-
	1°-5°N.	180°-172°W.	206,905	5.48	0.92	0.34	0.04	0.62	0.04	-
July	1°-5°N.	179°-171°W.	111,650	5.29	0.95	0.27	0.07	0.74	0.36	-
Aug.	6°-8°N.	178°-172°W.	194,220	0.86	1.84	0.04	0.06	1.07	-	<0.01
	2°-5°N.	179°-165°W.	318,760	2.87	0.91	0.09	0.05	1.13	-	-
Sept.	4°-8°N.	179°-154°W.	100,055	1.18	1.66	0.03	0.10	1.01	0.08	0.14
	2°-7°N.	179°-154°W.	230,155	2.58	0.86	0.28	-	0.80	0.02	0.09
	2°-8°N.	179°-154°W.	330,210	2.15	1.10	0.20	0.10	0.96	0.04	0.10
Oct.	5°-12°N.	179°-163°W.	253,412	0.87	1.04	0.05	-	0.74	0.09	-
	2°-5°N.	179°-166°W.	238,755	2.41	0.57	0.54	-	0.50	0.21	<0.01
Nov.	4°-11°N.	178°-168°W.	143,050	0.81	1.19	0.01	-	0.31	0.16	0.15
Dec.	No fishing east of 180° longitude in central Pacific waters.									

1/ Includes black marlin, white marlin, striped marlin, broadbill, sailfish

Table 13.--Results of Japanese exploratory tuna fishing in the central Pacific during 1953 (data from Iwate Prefecture 1953)

Station	Date	Position		Number of hooks	Catch per 100 hooks			
		Latitude	Longitude		Yellow-fin	Big-eye	Alba-core	Skip-jack
1	4-4-53	11°10'N.	176°10'W.	1765	0.11	1.59	-	0.23
2	4-6-53	09°18'N.	173°18'W.	1765	0.74	2.44	-	0.06
3	4-7-53	09°13'N.	173°24'W.	1695	0.18	1.30	-	0.06
4	4-8-53	09°34'N.	173°15'W.	1725	0.12	1.85	-	0.35
5	4-9-53	09°39'N.	173°05'W.	1565	0.70	0.70	-	0.32
6	4-11-53	10°30'N.	170°35'W.	1750	0.06	1.66	-	0.06
7	4-12-53	10°50'N.	170°45'W.	1750	0.17	0.97	-	0.06
8	4-13-53	10°50'N.	170°34'W.	1725	0.17	1.16	-	0.17
9	4-14-53	10°28'N.	170°45'W.	1675	0.66	2.27	-	0.60
10	4-15-53	10°29'N.	170°46'W.	1725	0.17	1.39	-	0.58
11	4-16-53	10°08'N.	170°59'W.	1725	0.06	1.04	-	0.12
12	4-18-53	10°27'N.	170°24'W.	1765	0.28	1.87	-	0.06
13	4-19-53	10°28'N.	170°38'W.	1750	0.40	2.17	-	0.11
14	4-20-53	10°28'N.	170°56'W.	1750	0.51	3.20	-	0.11
15	4-21-53	10°30'N.	170°51'W.	1740	0.34	1.89	-	0.11
16	4-22-53	10°30'N.	171°17'W.	1735	0.58	2.71	-	0.23
17	4-23-53	10°30'N.	171°29'W.	1720	0.41	2.50	-	0.29
18	4-24-53	10°17'N.	171°47'W.	1700	0.12	3.18	-	0.06
1	6-22-53	03°13'N.	176°25'W.	1730	5.72	0.81	0.35	0.06
2	6-23-53	03°45'N.	176°13'W.	1730	8.38	0.46	0.40	-
3	6-24-53	03°20'N.	175°57'W.	1730	4.57	1.27	0.35	-
4	6-25-53	03°42'N.	175°58'W.	1730	5.78	0.87	0.40	-
5	6-26-53	03°28'N.	176°46'W.	1730	9.25	0.81	0.23	0.06
6	6-27-53	03°48'N.	175°53'W.	1730	9.02	0.75	0.58	-
7	6-28-53	03°54'N.	175°51'W.	1625	5.97	0.98	0.12	0.12
8	6-29-53	04°10'N.	176°06'W.	1675	4.06	0.84	0.12	0.24
9	6-30-53	04°05'N.	176°06'W.	1730	4.10	1.04	0.17	-
10	7-1-53	04°05'N.	176°12'W.	1730	3.64	1.04	0.06	0.12
11	7-2-53	04°10'N.	176°24'W.	1725	5.21	0.87	0.06	0.06
12	7-3-53	04°06'N.	176°17'W.	1730	5.26	0.46	0.06	-

Table 14.--Lengths of yellowfin taken during 1953. Oceanic yellowfin are tabulated by longitude and month. The majority of the insular (within 80 miles from land) yellowfin were taken near the Line Islands

Midpoint (cm.)	140°W. March	150°W. Feb.	150°W. May	155°W. Aug.	155°W. Dec.	160°W. Aug.	170°W. June	Insular Jan.-Dec.
67	-	-	-	-	-	-	-	1
72	-	-	1	-	-	-	-	2
77	-	-	-	-	-	1	-	3
82	-	-	-	-	-	-	1	3
87	-	-	-	1	-	1	2	5
92	-	-	-	-	-	-	-	10
97	-	-	2	2	-	-	2	27
102	-	-	1	3	-	-	1	29
107	-	-	-	2	3	1	1	40
112	1	-	2	5	3	-	-	19
117	-	-	1	4	3	3	-	20
122	-	1	2	4	5	3	7	21
127	-	1	7	7	4	6	11	24
132	6	8	9	10	3	4	19	49
137	14	18	19	19	11	9	31	59
142	41	31	27	36	13	15	22	87
147	35	26	10	33	13	9	14	40
152	19	9	11	14	4	8	4	36
157	3	5	7	4	1	1	1	12
162	4	2	1	2	-	1	-	5
167	1	-	-	-	-	-	-	-

Table 15.--Length frequencies of tuna taken during 1953 arranged by sex

Mid-point (cm.)	Yellowfin		Bigeye		Albacore			Skipjack		
	♂	♀	♂	♀	Mid-point (cm.)	♂	♀	Mid-point (cm.)	♂	♀
67	2	-	-	-	78	1	-	47	1	-
72	1	2	-	-	79	-	1	48	-	1
77	2	2	1	-	82	1	-	52	-	1
82	2	2	-	-	83	-	1	53	1	-
87	2	7	-	-	85	-	1	55	-	1
92	4	6	1	1	86	-	1	56	-	1
97	20	13	1	1	87	-	6	60	1	-
102	17	17	3	-	88	-	1	61	1	-
107	24	23	3	3	89	-	3	64	-	1
112	14	16	1	1	90	1	-	67	-	1
117	13	18	2	2	91	1	5	68	-	1
122	23	20	1	3	92	2	10	70	-	3
127	31	29	8	4	93	1	8	71	-	3
132	61	48	3	2	94	10	8	72	2	4
137	76	106	5	1	95	7	7	73	1	3
142	154	119	10	5	96	5	1	74	2	1
147	150	30	7	2	97	6	1	75	1	4
152	94	12	10	4	98	6	4	76	5	-
157	30	4	12	5	99	3	1	77	1	3
162	14	1	5	4	100	11	-	78	4	3
167	-	1	10	3	101	6	-	79	-	1
172	-	-	9	1	102	14	1	80	6	1
177	-	-	3	1	103	5	-	81	1	1
182	-	-	3	-	104	1	-	82	-	2
					105	3	1	83	2	-
								84	1	-

Table 16.--Manning cruise 14, complete catch records (see table 6 for station locations) (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack)

A. Regular gear - six 15-fathom droppers per basket

ion	Number of baskets	YF	BE	Alb.	SJ	Marlin	Sharks			Others
							White-tipped	Silky	Great blue	
	39	-	-	-	-	7	-	-	-	4 1/
2	40	-	1	-	-	-	-	-	-	1 2/
3	40	-	-	-	-	-	-	-	-	2 2/
4	38	-	1	-	-	-	2	-	2	-
5	40	3	-	-	1	-	1	-	1	-
6	40	7	-	-	-	-	-	1	-	1 3/
7	40	4	-	-	2	-	1	3	1	2 4/
8	39	10	-	-	1	-	-	2	-	1 3/
9	40	2	-	-	-	-	3	-	-	-
1	40	10	1	-	3	-	6	1	-	-
2	40	10	3	-	-	-	3	-	-	1 5/
7	40	-	2	1	2	1	2	2	2	-
8	40	3	-	2	-	1	-	1	2	1 3/
9	40	4	2	-	-	2	2	-	-	-
0	40	3	-	6	1	-	-	-	3	-
1	40	3	-	3	-	2	4	-	-	-
2	40	1	-	3	-	3	2	-	-	4 6/
4	40	7	-	5	-	3	1	1	1	5 7/
5	40	2	1	11	-	3	7	-	-	-
6	40	19	2	-	-	1	11	-	1	2 8/
7	40	1	2	-	4	3	-	1	1	-
8	40	6	2	-	1	1	3	-	-	-
9	40	16	3	-	-	2	5	2	-	1 10/
2	40	15	6	-	-	-	2	1	1	1 9/
3	40	42	-	-	2	2	2	-	1	-
4	40	22	1	-	1	1	2	-	1	-
5	40	18	-	-	-	1	5	2	1	1 10/
6	40	12	4	-	2	2	1	3	1	3 11/
7	40	14	1	-	1	-	3	-	2	-

2 dolphin, 2 lancent fish; 2/ lancet fish; 3/ wahoo; 4/ mako shark, unidentified rk; 5/ unidentified shark-eaten tuna; 6/ barracuda; 7/ 3 wahoo, 1 lancet fish, nidentified shark-eaten tuna; 8/ 2 black-tipped sharks; 9/ sailfish; 10/ unidened shark; 11/ 2 wahoo, 1 lancet fish

Table 16.--Manning cruise 14, complete catch records (see table 6 for station locations) (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack) (cont'd)

B. Experimental gear - six 1-fathom droppers per basket

Station	Number of baskets	YF	BE	Alb.	SJ	Marlin	Sharks			Otl
							White-tipped	Silky	Great blue	
1	19	-	-	-	-	-	-	-	-	
2	20	-	1	-	-	1	-	-	-	
3	20	1	-	-	-	-	-	-	-	
7	20	6	1	-	1	1	-	-	-	
8	20	3	-	-	-	-	-	1	-	
10	20	3	-	-	-	1	1	-	-	
11	20	7	-	-	-	-	6	2	1	
12	20	2	-	-	2	1	-	-	-	
17	20	2	-	-	1	-	1	-	-	
18	20	5	-	-	-	1	-	-	-	
19	20	1	-	5	1	-	-	-	1	
20	20	9	-	-	-	-	-	-	1	
21	20	3	-	3	2	4	2	-	-	
22	20	-	-	-	-	-	6	-	-	

1/ 2 lancet fish, 1 dolphin

2/ dolphin, 2 short-nosed spearfish

3/ wahoo

4/ short-nosed spearfish

Table 16.--Manning cruise 14, complete catch records (see table 6 for station locations) (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack) (cont'd)

C. Complete catch records of special stations (10 baskets per group - 60 hooks)

12-hour series 1/										
ation	Group	Time started to haul	YF	BE	Alb.	SJ	Marlin	Sharks		Others
								White-tipped	Great blue	
14	I	0931	3	2	-	-	-	3	-	-
1°19'S.	II	1216	4	1	-	-	-	-	-	-
0°24'W.	III	1517	1	2	1	1	-	1	-	-
	IV	1720	4	5	-	-	1	5	-	1 2/
16	I	0913	2	-	-	-	-	-	-	-
1°25'S.	II	1209	-	1	-	-	-	3	-	-
0°45'W.	III	1512	1	-	-	-	-	1	-	-
	IV	1818	3	-	-	-	-	3	1	-

1/ All four groups set consecutively beginning at 0611 hours at station 14 0618 hours at station 16, then each group of 10 baskets was hauled as shown.

2/ unidentified shark

24-hour series								
Station	Group	Time started to set	Time started to haul	YF	BE	SJ	Sharks	
							White-tipped	Silky
15	I	0610	0914	2	-	-	3	-
01°19'S.	II	1006	1319	1	-	-	4	-
50°36'W.	III	1405	1715	1	-	1	3	-
	IV	1806	2126	-	2	-	-	-
	V	2219	0117	-	-	-	-	-
	VI	0204	0519	-	-	-	6	1
30	I	0613	0921	-	-	-	7	-
1°48'S.	II	1002	1326	2	-	-	10	-
39°59'W.	III	1410	1729	3	-	-	1	-
	IV	1758	2126	-	-	-	1	1
	V	2208	0130	-	-	-	2	-
	VI	0208	0532	-	-	-	3	-

Table 17.--Smith cruise 19, complete catch records (see table 7 for station locations)

A. Regular gear - six 15-fathom droppers per basket

Station	Number of baskets	Yellowfin	Bigeye	Marlin	Sharks			Others
					White-tipped	Silky	Great blue	
53	40	29	-	-	-	11	-	-
56	40	7	-	1	-	3	-	-
58	40	5	-	-	1	2	1	1[1/]
60	40	-[2/]	-	1	-	1	2	-
62	40	4[2/]	-	-	2	5	-	1[3/]
63	40	18	-	1	-	7	-	3[4/]
68	40	11	1	-	-	6	-	1[5/]

[1/] lancet fish
[2/] includes 1 yellowfin caught on end hook
[3/] wahoo
[4/] 2 unidentified sharks, 1 thresher shark
[5/] unidentified shark

B. Experimental gear - six 1-fathom droppers per basket

Station	Number of baskets	Yellowfin	Skipjack	Marlin	Sharks		Others
					Silky	Great blue	
53	10	14	-	-	6	-	-
56	10	7[1/]	-	1	5	-	-
58	10	6[1/]	-	-	-	1	-
60	10	-	1	-	-	2	-
62	10	5	-	-	-	-	-[2/]
63	10	13[1/]	-	-	5	-	1[2/]
68	10	8	-	-	4	-	-

[1/] includes 1 yellowfin caught on end hook
[2/] unidentified shark

Table 17.--Smith cruise 19, complete catch records (see table 7 for station locations) (cont'd)

C. Complete catch records of special stations (10 baskets per group - 60 hooks)

12-hour series[1]					
Station	Group	Time started to haul	Yellowfin	Silky shark	Others
66 01°59'N. 157°31'W.	I II III IV	0817 1106 1352 1702	20 10 11 6	- 7 3 3	- 1[2] - -

[1] All four groups set as a unit beginning at 0507 hours, then each group of 10 baskets was hauled as shown

[2] wahoo

Table 18.--Manning cruise 15, complete catch records (see table 8 for station locations) (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack)

A. Regular gear - six 15-fathom droppers per basket

Station	Number of baskets	YF	BE	Alb.	SJ	Marlin	Sharks			Other
							White-tipped	Silky	Great blue	
1	40	-	-	-	-	-	-	-	-	2 1/
2	40	-	1	-	-	-	3	-	7	5 2/
3	40	1	9	-	-	-	-	-	2	2 3/
5	40	4	7	-	-	-	-	2	-	1 4/
6	40	1	7	-	-	-	1	1	-	1 5/
7	39	24	-	3	3	-	1	2	-	2 6/
8	40	19	-	3	1	1	-	1	-	3 7/
10	40	5	-	1	1	-	-	1	1	-
11	40	4	-	-	-	-	10	7	-	1 8/
12	40	6	-	2	1	-	2	1	-	-
13	40	-	4	-	2	-	8	1	-	1 9/
14	40	6	-	4	-	2	1	-	-	1 10/
15	40	1	2	5	-	3	1	1	1	1
16	40	4	2	5	1	1	5	-	4	-
17	40	5	-	9	-	-	3	-	-	1 8/
18	40	1	4	17	2	1	16	-	2	-
19	40	15	-	5	-	-	9	-	4	1 8/
20	41	2	1	7	-	-	1	1	4	-
21	40	5	-	2	1	1	2	-	-	1 9/
22	40	18	-	-	1	1	3	-	1	1 4/
23	40	13	-	-	-	-	1	3	3	-
24	40	17	-	-	-	1	2	2	1	-
25	40	19	-	-	1	1	-	-	2	1 10/
26	40	17	-	-	-	1	1	-	4	-
27	40	4	-	-	-	1	2	2	-	1 10/
28	40	3	5	-	1	-	1	-	2	1 5/
29	40	3	4	-	-	3	1	1	1	-

1/ dolphin; 2/ 1 mako shark, 1 dolphin, 2 lancet fish, 1 short-nosed spearfish; 3/ 1 thresher shark, 1 lancet fish; 4/ mako shark; 5/ 2 lancet fish; 6/ 2 mako sharks, 1 lancet fish; 7/ unidentified shark; 8/ short-nosed spearfish; 9/ barracuda; 10/ wahoo

Table 18.--Manning cruise 15, complete catch records (see table 8 for station locations) (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack) (cont'd)

B. Experimental gear - eleven 3-fathom droppers per basket

n	Number of baskets	YF	BE	Alb.	SJ	Marlin	Sharks			Others
							White-tipped	Silky	Great blue	
	10	-	-	-	-	-	-	-	-	-
	10	-	-	-	-	1	-	-	1	2[1/]
	10	1	1	-	-	-	-	1	-	-
	10	-	2	-	-	-	-	-	3	1[2/]
	10	-	1	-	-	1	-	1	1	2[3/]
	10	14	1	3	3	-	-	1	-	-
	10	4	-	1	-	-	-	-	-	-
	10	5	-	-	-	-	-	-	-	1[4/]
	10	3	-	-	-	-	2	2	-	-
	10	5	1	1	3	-	1	-	-	-
	10	-	-	-	-	-	2	2	-	-
	11	-	-	3	-	1	-	-	1	1[5/]
	10	-	-	1	-	3	-	-	-	-
	10	-	-	2	-	-	5	-	1	-
	10	-	-	3	-	-	-	-	-	-
	10	4	-	11	-	-	-	-	-	-
	10	2	-	6	-	-	3	-	-	-
	10	4	-	3	-	-	-	1	-	-
	10	5	-	1	-	-	1	-	-	-
	10	5	-	-	-	-	1	1	-	-
	10	9	-	-	1	-	1	5	-	-
	10	3	-	-	-	-	1	-	1	-
	10	5	-	-	-	1	-	-	-	-
	10	1	-	-	-	-	-	1	-	-
	10	3	-	-	-	-	-	-	-	-
	10	-	1	-	-	-	-	-	-	-
	10	-	4	-	-	-	-	-	-	-

1/ lancet fish, short-nosed spearfish
2/ unidentified shark-eaten tuna
3/ dolphin, mako shark
4/ wahoo
5/ lancet fish

Table 18.--Manning cruise 15, complete catch records (see table 8 for station locations) (YF=yellowfin, BE=bigeye, Alb.= albacore, SJ=skipjack) (cont'd)

C. Complete catch records of special stations (10 baskets per group - 60 hooks)

24-hour series[1/]										
Station	Group	Time started to set	Time started to haul	YF	BE	Alb.	SJ	Sharks		Othe
								White-tipped	Silky	
9	I	0633	0933	2	-	-	-	7	1	-
02°52'N.	II	1029	1329	4	-	-	-	3	-	-
149°52'W.	III	1415	1714	1	-	3	2	1	-	-
	IV	1804	2120	-	-	-	-	3	-	-
	V	2226	0145	-	-	-	-	2	-	-
	VI	0240	0550	-	-	-	-	2	-	1[2/]

[1/] each group of 10 baskets allowed to soak for approximately three hou

[2/] 1 broadbill swordfish

ble 19.--Manning cruise 16, complete catch records (see table 9 for station locations) (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack)

A. Regular gear - six 15-fathom droppers per basket

n	Number of baskets	YF	BE	Alb.	SJ	Marlin	Sharks			Others
							White-tipped	Silky	Great blue	
	29	-	-	-	-	-	-	-	-	4 1/
	31	-	2	-	-	-	4	1	5	3 2/
	32	-	1	-	-	1	2	2	3	6 3/
	30	1	4	-	1	-	-	5	5	3 4/
	30	13	-	-	-	-	2	4	-	-
	30	9	-	-	1	-	1	-	-	-
	28	22	1	1	-	-	2	-	1	-
	30	14	1	1	-	-	-	1	-	-
	30	11	2	1	-	1	-	3	1	-
	29	28	-	1	-	-	-	9	-	-
	30	19	-	-	-	-	-	20	-	-
	26	6	1	-	-	-	-	3	-	-
	30	12	-	-	1	1	1	1	2	-
	30	5	-	7	-	-	3	2	1	-
	30	1	-	-	-	2	1	1	-	-
	30	5	-	1	-	2	2	-	1	2 5/
	30	3	-	1	-	-	-	-	1	1 6/
	30	17	1	3	-	-	2	2	-	-
	30	6	-	-	1	-	2	3	-	1 5/
	30	10	-	-	-	1	1	3	-	-
	30	3	-	1	-	-	1	1	1	-
	30	2	-	-	-	-	1	2	-	-
	30	8	-	-	-	-	-	3	-	-
	30	6	-	-	1	1	-	-	-	-
	30	1	-	-	-	-	1	1	1	1 7/
	30	-	4	-	1	-	1	2	2	5 8/

1/ 3 lancet fish, 1 sailfish
2/ 1 wahoo, 2 lancet fish
3/ 1 wahoo, 3 dolphins, 2 sailfish
4/ 1 wahoo, 1 lancet fish, 1 dolphin
5/ barracuda
6/ broadbill swordfish
7/ lancet fish
8/ 1 mako shark, 2 lancet fish, 2 sailfish

Table 19.--Manning cruise 16, complete catch records (see table 9 for station locations) (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack) (cont'd)

B. Experimental gear - eleven 1-fathom droppers per basket

Station	Number of baskets	YF	BE	Alb.	SJ	Marlin	Sharks			Other
							White-tipped	Silky	Great blue	
1	19	-	-	-	-	-	-	1	-	1 1/
2	19	-	1	-	-	-	-	-	3	2 2/
4	17	1	3	-	-	2	1	-	-	2 3/
6	20	1	4	-	-	1	-	2	-	1 4/
8	20	7	4	-	-	-	2	1	1	-
9	20	2	-	-	-	1	1	2	1	1 4/
10	19	14	-	-	-	1	-	-	-	-
11	15	2	-	-	-	-	1	-	2	-
12	20	14	-	-	-	-	-	2	-	2 7/
13	20	16	-	1	-	2	-	4	-	-
14	18	21	-	-	-	-	-	10	-	1 5/
16	20	7	1	-	-	-	-	-	-	-
17	20	13	-	-	-	-	2	1	-	-
18	20	8	-	3	2	-	-	-	-	-
19	20	4	-	-	-	-	1	-	-	-
20	20	3	-	1	-	3	1	-	2	1 1/
21	20	6	-	4	2	-	-	-	1	-
22	20	5	-	1	1	-	1	-	-	-
23	20	5	-	-	-	-	-	2	-	-
24	20	13	-	-	-	1	-	1	-	-
25	20	2	-	-	-	-	-	3	-	-
26	20	8	-	-	-	-	1	2	-	-
27	20	5	1	-	1	-	-	3	-	1 6/
28	20	2	-	-	-	2	-	-	-	-
29	20	1	6	-	-	-	2	1	-	1 6/
30	20	2	1	-	-	1	1	1	1	2 3/

1/ barracuda
2/ 1 lancet fish, 1 wahoo
3/ 1 lancet fish, 1 sailfish
4/ wahoo
5/ thresher shark
6/ mako shark
7/ unidentified shark-bitten tuna, wahoo

Table 19.--Manning cruise 16, complete catch records (see table 9 for station locations) (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack) (cont'd)

C. Experimental gear - twenty-one 3-fathom droppers per basket

ion	Number of baskets	YF	BE	Alb.	SJ	Marlin	Sharks			Others
							White-tipped	Silky	Great blue	
1	10	-	-	-	-	-	-	-	-	-
2	10	-	2	-	-	1	1	-	3	1 1/
4	10	-	3	-	-	-	2	1	1	1 2/
6	10	-	3	-	-	1	-	3	2	2 3/
8	10	8	3	-	-	-	-	3	2	-
9	9	3	1	-	-	-	-	1	-	-
0	6	9	-	1	-	-	-	1	1	-
1	5	4	-	-	-	-	-	-	-	1 3/
2	5	3	-	-	-	-	-	2	-	-
3	5	20	-	2	-	-	-	6	-	-
4	4	11	-	-	-	-	-	10	-	1 4/
6	10	1	-	1	1	-	-	2	1	-
4	10	11	-	-	-	-	1	-	-	-
5	10	3	-	-	1	-	-	-	1	-
6	10	12	-	-	-	1	2	-	-	-
7	10	13	1	-	-	1	-	4	-	-
8	10	3	-	-	-	1	-	1	1	-
9	10	1	-	-	1	-	-	-	-	3 5/

1/ wahoo

2/ lancet fish

3/ barracuda

4/ thresher shark

5/ dolphin

Table 20.--Manning cruise 17, complete catch records (see table 10 for station locations) (YF=yellowfin, BE=bigeye, Alb.= albacore, SJ=skipjack)

A. Regular gear - six 15-fathom droppers per basket

Station	Number of baskets	YF	BE	Alb.	SJ	Marlin	Sharks		Other
							Silky	Great blue	
2	30	13	1	-	-	-	2	1	-
3	30	10	-	-	-	1	3	-	-
4	21	13	-	-	-	-	11	-	-
5	20	15	2	2	1	-	2	-	1[1/]
6	19	8	-	1	-	-	1	-	-
7	19	13	-	1	-	1	4	-	-

[1/] wahoo

B. Experimental gear - eleven 3-fathom droppers per basket

Station	Number of baskets	YF	BE	SJ	Marlin	Sharks			Others
						White-tipped	Silky	Great blue	
2	30	10	-	3	1	2	1	1	1[1/]
3	30	8	-	-	1	-	7	-	-
4	22	14	-	-	1	-	8	-	2[2/]
5	20	15	2	-	2	-	2	-	-
6	21	15	1	-	1	-	3	-	1[3/]
7	21	15	-	-	-	-	4	-	-

[1/] lancet fish

[2/] 1 thresher shark, 1 unidentified shark

[3/] unidentified shark-eaten tuna

ble 21.--Manning cruise 18, complete catch records (see table 11 for station locations) (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack)

A. Regular gear - six 15-fathom droppers per basket

n	Number of baskets	YF	BE	Alb.	SJ	Marlin	Sharks			Others
							White-tipped	Silky	Great blue	
	30	6	-	1	-	2	3	-	-	1 1/
	30	4	1	-	-	-	-	2	-	-
	30	15	-	-	-	-	4	2	1	1 2/
	30	-	-	-	-	-	6	2	-	-
	30	4	-	-	1	-	4	8	-	-
	30	4	-	-	-	-	6	5	1	2 3/
	30	5	-	-	1	-	2	7	-	-
	30	24	-	-	-	-	1	5	-	-
	30	5	-	-	-	-	-	1	2	-
	30	2	-	-	-	1	4	-	-	-
	30	4	-	-	-	-	1	2	1	1 2/
	30	1	-	-	-	-	3	2	1	1 2/
	30	-	2	-	1	-	2	-	4	3 4/
	30	-	-	-	-	-	-	2	-	5 5/

wahoo

lancet fish

sailfish

2 lancet fish, 1 wahoo

2 dolphins, 3 thresher sharks

Table 21.--Manning cruise 18, complete catch records (see table 11 for station locations) (YF=yellowfin, BE=bigeye, Alb.=albacore, SJ=skipjack) (cont'd)

B. Experimental gear - eleven 3-fathom droppers per basket

Station	Number of baskets	YF	BE	Alb.	SJ	Marlin	Sharks			Oth
							White-tipped	Silky	Great blue	
2	30	4	-	1	2	-	-	2	-	
5	30	4	-	-	-	-	-	2	-	
8	30	11	1	-	-	-	2	-	-	
10	30	-	-	-	-	2	6	3	-	
12	30	6	-	-	-	-	5	8	-	
14	30	12	-	-	-	-	9	11	1	
16	30	17	1	-	-	-	8	7	-	
18	30	22	-	-	-	1	-	5	1	
19	30	6	-	-	-	-	-	5	-	
21	30	11	1	-	-	-	2	4	-	
23	30	3	-	-	-	-	2	5	-	
25	30	1	1	-	-	-	1	-	1	
27	30	-	1	-	-	-	5	1	1	
29	30	-	-	-	1	-	-	1	1	

1/ lancet fish

2/ bonito shark

3/ dolphin

4/ sailfish

5/ wahoo

6/ 3 lancet fish, 1 wahoo

7/ 1 dolphin, 2 lancet fish, 1 thresher shark

Table 22.--Manning cruise 14, time taken setting and hauling [illegible]

Station	Set			Haul					Fish-handling break3/
					Regular gear1/		Experimental gear2/		
	Number of baskets	Time started to set	Time taken for setting	Time started to haul	Number of baskets	Time taken for hauling	Number of baskets	Time taken for hauling	
			min.			min.		min.	min.
1	60	0617	73	1215	40	242	20	119	30
2	60	0630	68	1200	40	195	20	81	31
3	60	0629	71	1205	40	169	20	104	33
4	40	0635	50	1222	40	169	-	-	34
5	40	0625	52	1222	40	135	-	-	34
6	40	0627	43	1222	40	172	-	-	39
7	60	0620	63	1232	40	158	20	98	87
8	59	0629	67	1106	39	170	20	113	35
10	60	0612	66	1201	40	171	20	90	56
11	60	0615	66	1202	40	160	20	77	68
12	60	0630	67	1213	40	161	20	90	84
17	60	0610	74	1210	40	145	20	77	70
18	60	0603	66	1152	40	142	20	80	74
19	60	0612	65	1210	40	158	20	71	62
20	60	0715	67	1200	40	146	20	76	68
21	60	0610	68	1209	40	130	20	86	24
22	60	0605	68	1208	40	143	20	65	67
24	40	0603	45	1203	40	198	-	-	77

1/ Six 15-fathom droppers per basket
2/ Six 1-fathom droppers per basket
3/ Break came midway during the hauling period

Table 22.--Manning cruise 14, time taken setting and hauling the longline (cont'd)

Station	Set			Haul					Fish-handling break[3/]
	Number of baskets	Time started to set	Time taken for setting	Time started to haul	Regular gear[1/] Number of baskets	Regular gear[1/] Time taken for hauling	Experimental gear[2/] Number of baskets	Experimental gear[2/] Time taken for hauling	
			min.			min.		min.	min.
25	40	0551	48	1201	40	151	-	-	65
26	40	0556	47	1201	40	150	-	-	68
27	40	0600	45	1214	40	157	-	-	67
28	40	0555	48	1201	40	135	-	-	68
29	40	0554	46	1214	40	159	-	-	60
32	40	0559	44	1202	40	147	-	-	83
33	40	0601	43	1206	40	189	-	-	73
34	40	0604	45	1202	40	173	-	-	60
35	40	0559	37	1201	40	136	-	-	66
36	40	0602	41	1216	40	154	-	-	60
37	40	0600	40	1205	40	162	-	-	54
Average time per basket			1.1 min.			4.0 min.		4.4 min.	

1/ Six 15-fathom droppers per basket
2/ Six 1-fathom droppers per basket
3/ Break came midway during the hauling period

Table 23.--Smith cruise 19, time taken setting and hauling the longline

Station	Set[1]		Haul			Fish-handling break[4]
	Time started to set	Time taken for setting	Time started to haul	Time taken for hauling regular gear[2]	Time taken for hauling experimental gear[3]	
		min.		min.	min.	min.
53	0604	63	1230	163	69	35
56	0725	60	1309	145	44	38
58	0600	59	1246	148	51	41
60	0605	61	1250	281	117	42
62	0559	59	1247	161	39	47
63	0612	113	1251	164	48	39
68	0609	59	1233	153	38	43
Average time per basket		1.4 min.		4.3 min.	5.8 min.	

[1] 40 baskets of regular gear and 10 baskets of experimental gear set at each station

[2] Six 15-fathom droppers per basket

[3] Six 1-fathom droppers per basket

[4] Break came midway during the hauling period

Table 24. --Manning cruise 15, time taken setting and hauling the longline

Station	Time started to set	Time started to haul	Regular gear[1/]		Experimental gear[2/]		Fish-handling break[3/]
			Time taken for setting	Time taken for hauling	Time taken for setting	Time taken for hauling	
			min.	min.	min.	min.	min.
1	0915	1232	49	194	21	39	27
2	0600	1239	40	-	20	50	-
3	0603	1244	40	176	19	91	35
5	0608	1239	38	167	17	46	27
6	0608	1224	41	183	17	56	27
7	0604	1238	38	201	17	39	30
8	0603	1211	39	169	19	50	30
10	0602	1217	41	151	17	34	-
11	0602	1231	40	184	16	39	28
12	0600	1227	40	166	16	52	33
13	0605	1226	38	169	15	33	31
14	0603	1229	37	160	16	41	31
15	0601	1224	37	160	15	29	27
16	0605	1221	40	153	15	33	33
17	0634	1254	50	111	20	29	30
18	0624	1234	36	187	15	36	43
19	0628	1229	35	179	15	33	38
20	0629	1222	43	146	15	34	28

[1/] Six 15-fathom droppers per basket. Set 40 baskets of gear at each station; exceptions - station 7 with 39 baskets and station 20 with 41 baskets

[2/] Eleven 3-fathom droppers per basket. Set 10 baskets of gear at each station; exception - station 14 with 11 baskets

[3/]

Table 24.--Manning cruise 15, time taken setting and hauling the longline (cont'd)

Station	Time started to set	Time started to haul	Regular gear[1]		Experimental gear[2]		Fish-handling break[3]
			Time taken for setting	Time taken for hauling	Time taken for setting	Time taken for hauling	
			min.	min.	min.	min.	min.
21	0622	1226	42	141	14	35	51
22	0632	1239	39	166	14	50	33
23	0623	1239	39	133	14	54	39
24	0620	1240	41	143	13	41	33
25	0626	1225	41	160	15	41	32
26	0621	1232	42	142	13	50	46
27	0625	1221	39	148	12	34	34
28	0623	1232	42	168	14	39	38
29	0623	1227	39	171	12	50	35
Average time per basket			1.0 min.	4.1 min.	1.6 min.	4.3 min.	

[1] Six 15-fathom droppers per basket. Set 40 baskets of gear at each station; exceptions - station 7 with 39 baskets and station 20 with 41 baskets

[2] Eleven 3-fathom droppers per basket. Set 10 baskets of gear at each station; exception - station 14 with 11 baskets

[3] Break came midway during the hauling period

Table 25.--Manning cruise 16, time taken setting and hauling the longline

Station	Set			Haul							Fish-handling break
					Regular gear 1/		11-hook gear 2/		21-hook gear 3/		
	Number of baskets	Time started to set	Time taken for setting	Time started to haul	Number of baskets	Time taken for hauling	Number of baskets	Time taken for hauling	Number of baskets	Time taken for hauling	
			min.			min.		min.		min.	min.
1	58	0626	73	1244	29	112	19	69	10	47	32
2	60	0622	74	1230	31	158	19	99	10	58	37
4	59	0639	67	1230	32	132	17	91	10	51	25
6	60	0620	66	1227	30	141	20	84	10	52	33
8	60	0621	78	1232	30	140	20	84	10	84	36
9	60	0617	71	1234	30	120	20	66	10	93	36
10 4/	60	0620	70	1232	28	148	19	147	6	49	33
11	50	0623	56	1240	30	128	15	51	5	30	30
12	55	0629	59	1237	30	145	20	92	5	27	30
13 5/	55	0618	57	1240	29	130	20	128	5	33	32
14	53	0627	56	1308	30	119	18	104	5	108	28
16	56	0625	62	1234	26	110	20	86	10	59	36
17	50	0635	62	1230	30	138	20	86	-	-	35
18	50	0625	70	1240	30	122	20	77	-	-	36
19	50	0625	66	1231	30	130	20	73	-	-	48
20	50	0629	59	1234	30	126	20	93	-	-	37
21	50	0636	61	1228	30	132	20	73	-	-	42

1/ Six 15-fathom droppers per basket
2/ Eleven 3-fathom droppers per basket
3/ Twenty-one 3-fathom droppers per basket
4/ Lost two regular gear baskets, one 11-hook gear basket, three one-half 21-hook

Table 25.--Manning cruise 16, time taken setting and hauling the longline (cont'd)

Station	Set			Haul							Fish-handling break
	Number of baskets	Time started to set	Time taken for setting	Time started to haul	Regular gear 1/ Number of baskets	Regular gear 1/ Time taken for hauling	11-hook gear 2/ Number of baskets	11-hook gear 2/ Time taken for hauling	21-hook gear 3/ Number of baskets	21-hook gear 3/ Time taken for hauling	
			min.			min.		min.		min.	min.
22	50	0635	61	1240	30	114	20	86	-	-	31
23	50	0632	63	1242	30	150	20	89	-	-	64
24	60	0633	82	1221	30	127	20	84	10	69	49
25	60	0633	84	1230	30	122	20	59	10	50	46
26	60	0636	84	1248	30	123	20	70	10	55	36
27	60	0637	79	1250	30	141	20	73	10	64	28
28	60	0637	83	1249	30	100	20	69	10	51	41
29	60	0637	84	1249	30	109	20	68	10	46	42
30	50	0631	64	1250	30	133	20	87	-	-	41
Average time per basket			1.2			4.3		4.3		6.6	

1/ Six 15-fathom droppers per basket
2/ Eleven 3-fathom droppers per basket
3/ Twenty-one 3-fathom droppers per basket

Table 26.--Manning cruise 17, time taken setting and hauling the longline

Station	Set			Haul					Fish-handling break
	Number of baskets	Time started to set	Time taken for setting	Time started to haul	Regular gear[1] Number of baskets	Regular gear[1] Time taken for hauling	11-hook gear[2] Number of baskets	11-hook gear[2] Time taken for hauling	
			min.			min.		min.	min.
2	60	0648	74	1224	30	111	30	179	34
3	60	0619	67	1221	30	126	30	141	29
4[3]	60	0628	69	1224	21	118	22	183	30
5	40	0629	49	1236	20	83	20	113	36
6	40	0626	47	1230	19	78	21	117	31
7	40	0625	49	1223	20	81	20	100	34
Average time per basket			1.2 min.			4.3 min.		5.8 min.	

[1] Six 15-fathom droppers per basket
[2] Eleven 3-fathom droppers per basket
[3] Lost 17 baskets of gear

Table 27.--Manning cruise 16, time taken [illegible]

Station	Set			Haul			Fish-handling break
	Number of baskets[1]	Time started to set	Time taken for setting	Time started to haul	Time taken for hauling regular gear[2]	Time taken for hauling 11-hook gear[3]	
			min.		min.	min.	min.
2	60	0700	72	1209	111	105	34
5	60	0621	67	1211	106	93	34
8	60	0625	65	1222	114	97	35
10	60	0615	70	1216	112	103	30
12	60	0628	69	1222	114	100	33
14	60	0625	69	1218	133	134	35
16	60	0620	69	1221	126	144	29
18	60	0620	70	1210	107	99	35
19	60	0626	69	1206	105	103	29
21	60	0628	69	1219	122	116	29
23	60	0617	70	1217	104	100	36
25	60	0623	71	1220	116	104	32
27	60	0620	67	1141	109	102	24
29[4]	60	0629	66	1203	126	112	22
Average time per basket			1.1 min.		3.8 min.	3.6 min.	

[1] 30 baskets of each type of gear set at each station
[2] Six 15-fathom droppers per basket
[3] Eleven 3-fathom droppers per basket
[4] Last 15 baskets hauled in at slow speed due to mechanical failure

Table 28.--Average wind direction and Beaufort force at the fishing stations[1/]

A. Oceanic stations (more than 80 miles from land)

Latitude	JRM 14 150°W. Jan.-Feb.	JRM 14 140°W. March	JRM 15 150°W. May	JRM 15 170°W. May-June	JRM 16 155°W. July	JRM 16 160°W. August	JRM 155° Dec
16°N.	W-1	-	-	-	-	-	-
15°N.	-	-	-	-	-	-	-
14°N.	-	-	-	-	-	-	-
13°N.	-	-	-	-	-	-	-
12°N.	E-5	-	-	-	-	-	-
11°N.	-	-	-	-	-	-	-
10°N.	-	-	NE-5	-	SE-3	-	-
9°N.	-	-	NE-4	-	-	E-3	-
8°N.	-	-	-	NE-3	E-2	S-2	SE-
7°N.	NE-5	-	NE-4	-	E-3	-	SE-
6°N.	-	-	?-2	E-4	E-3	SE-4	SE-
5°N.	NE-4	-	-	E-4	SE-3	-	-
4°N.	NE-4	NE-4	E-3	E-5	-	-	SE-
3°N.	E-3	NE-3	NE-3	E-3	SE-5	-	SE-
2°N.	E-2	N-4	NE-4	E-3	E-5	E-4	E-3
1°N.	E-2	E-3	NE-3	E-2	SE-5	E-3	E-3
Q	E-3	NE-4	-	-	E-4	-	E-4
1°N.	E-2; NE-5	NE-4	NE-2	E-2	E-5	-	E-4
2°N.	NE-4	NE-3	NE-1	-	-	-	-
3°N.	E-4	E-4	-	-	E-5	NE-3	-
4°N.	E-3	-	NE-1	-	-	-	-
5°N.	-	NE-2	N-2	-	-	-	-
6°N.	E-3	E-3	NE-2	N-2	-	-	-
7°N.	E-2	-	-	N-1	-	-	-

[1/] Averages obtained by taking three station observations (morning, noon and after hauling) and determining; (1) the general direction of the wind using eight compass points, (2) averaging the Beaufort code values.

Table 28.--Average wind direction and Beaufort force at the fishing stations[1/] (cont'd)

B. Insular stations (less than 80 miles from land)

Vessel and cruise	Station	Wind direction	Beaufort force
Smith 19	53	NE	5
	56	S	4
	58	SE	4
	60	SE	4
	62	E	4
	63	E	3
	68	E	4
Manning 14	22	SE	3
	24	NE	4
Manning 15	19	NE	3
	20	NE	2
	21	NE	2
Manning 16	12	E	4
	13	E	4
	14	E	4
	20	E	3
	22	NE	3
	23	NE	4
	26	E	4
	27	SE	3
Manning 17	2	SE	3
	3	E	2
	4	SE	3
	5	SE	4
	6	SE	2
	7	E	2
Manning 18	2	E	5
	5	E	4
	16	E	4
	18	E	4
	19	E	4

[1/] Averages obtained by taking three station observations (morning, noon and after hauling) and determining; (1) the general direction of the wind using eight compass points, (2) averaging the Beaufort code values.

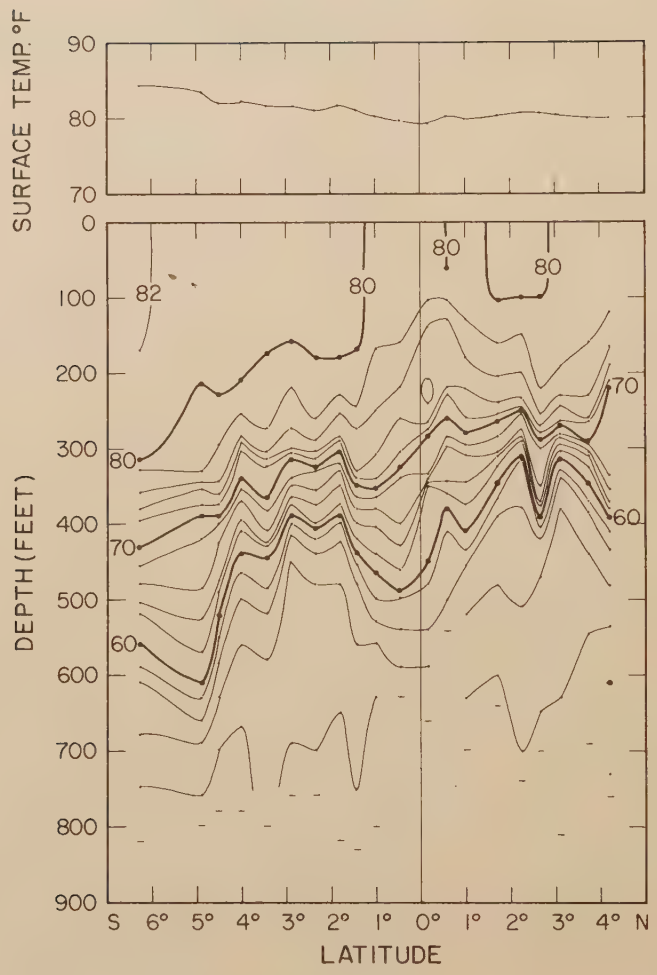

Figure 13.--Surface temperatures and vertical temperature section along 140°W. longitude, March 1953 (Manning cruise 14). Upper panel--surface temperatures as read at each bathythermograph lowering. Lower panel--temperature section based on bathythermograph lowerings; isotherms at 2°F. intervals, depth of lowering shown by small horizontal dashes.

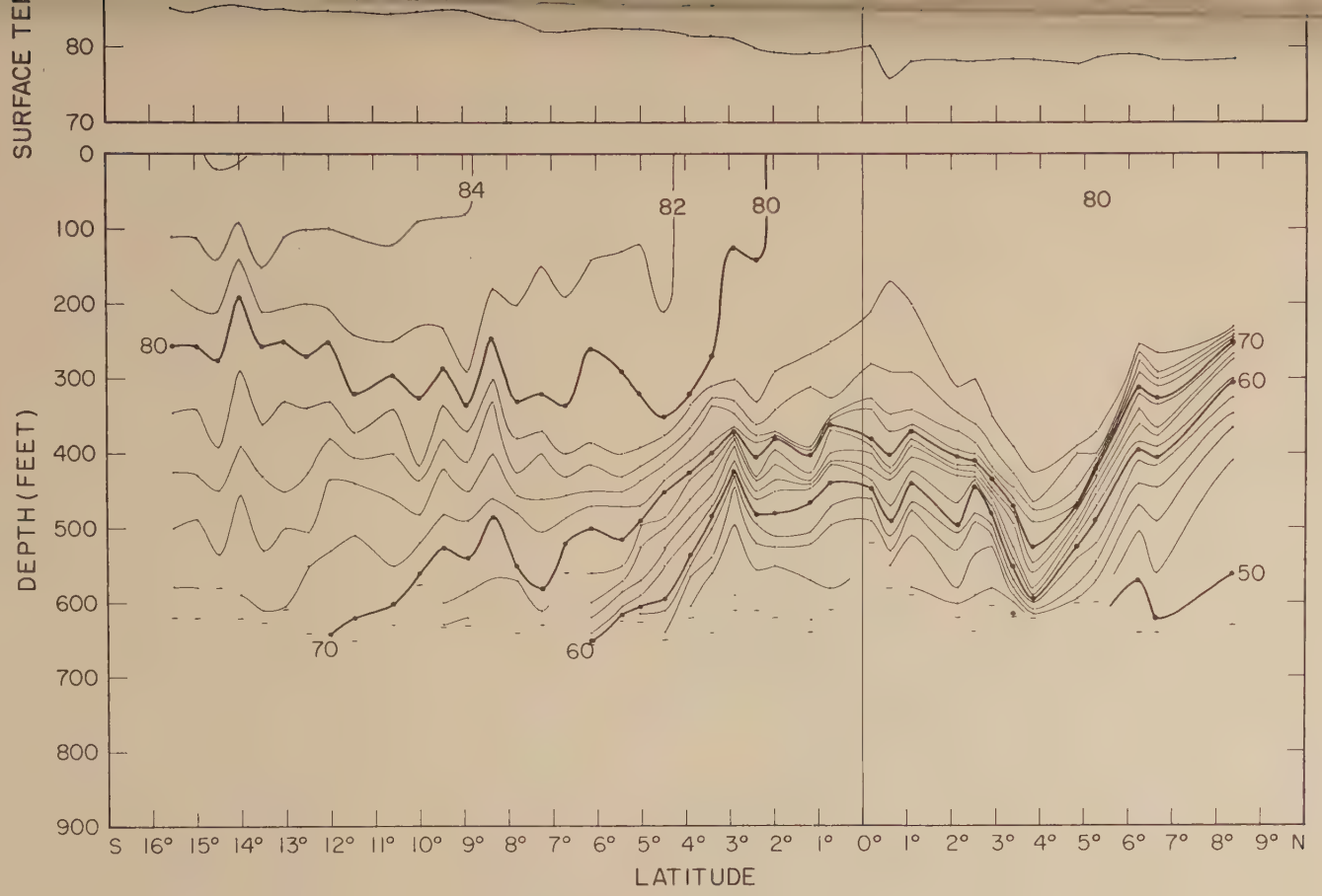

Figure 14.--Surface temperatures and vertical temperature section along 150°W. longitude, February 1953 (Manning cruise 14). Upper panel--surface temperatures as read at each bathythermograph lowering. Lower panel--temperature section based on bathythermograph lowerings; isotherms at 2°F. intervals, depth of lowering shown by small horizontal dashes.

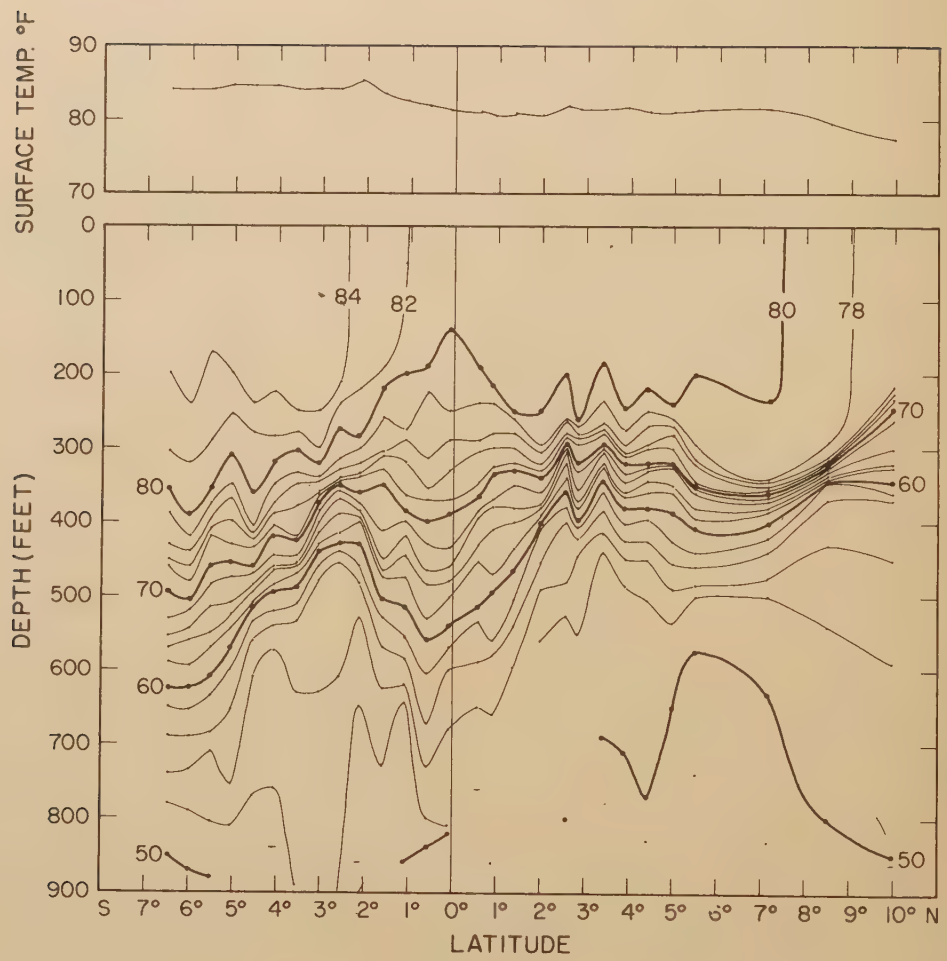

Figure 15. --Surface temperatures and vertical temperature section along 150°W. longitude, May 1953 (Manning cruise 15). Upper panel--surface temperatures as read at each bathythermograph lowering. Lower panel--temperature section based on bathythermograph lowerings; isotherms at 2°F. intervals, depth of lowering shown by small horizontal dashes.

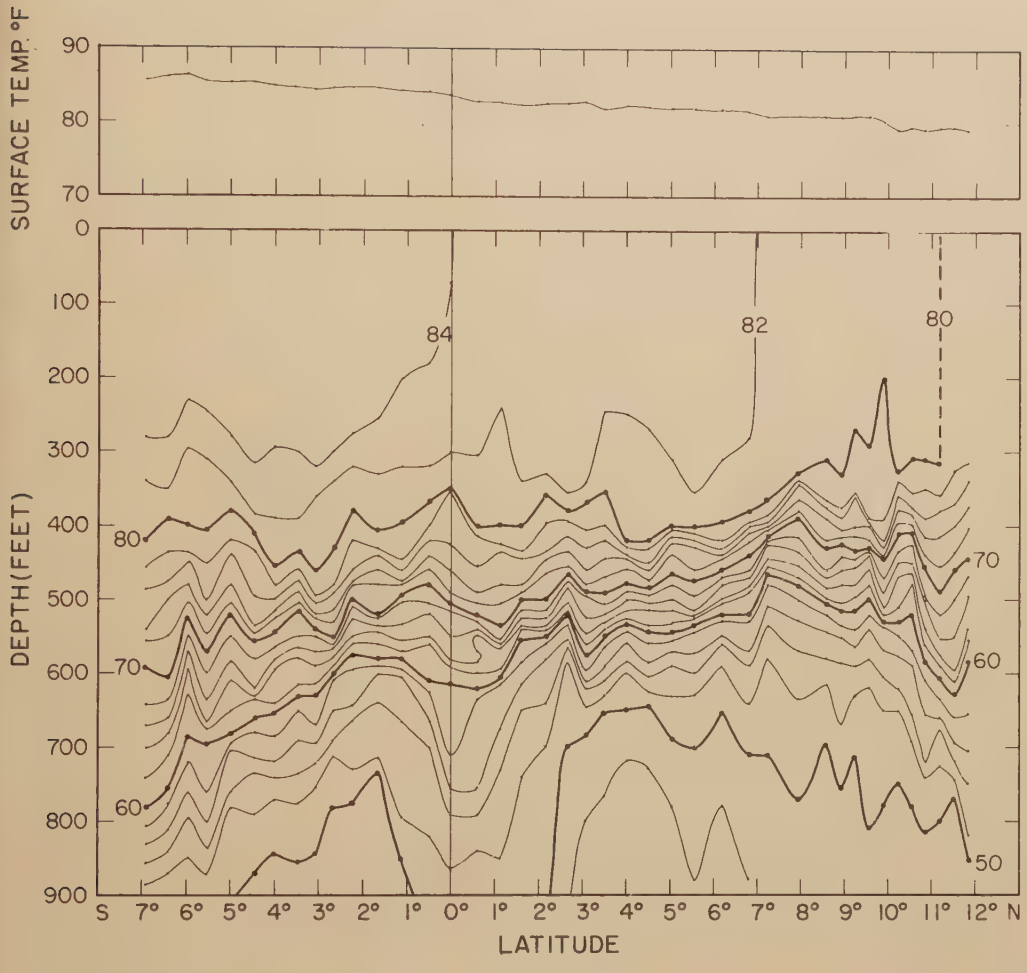

Figure 16.--Surface temperatures and vertical temperature section along 170°W. longitude, June 1953 (Manning cruise 15). Upper panel--surface temperatures as read at each bathythermograph lowering. Lower panel--temperature section based on bathythermograph lowerings; isotherms at 2°F. intervals, depth of lowering shown by small horizontal dashes.

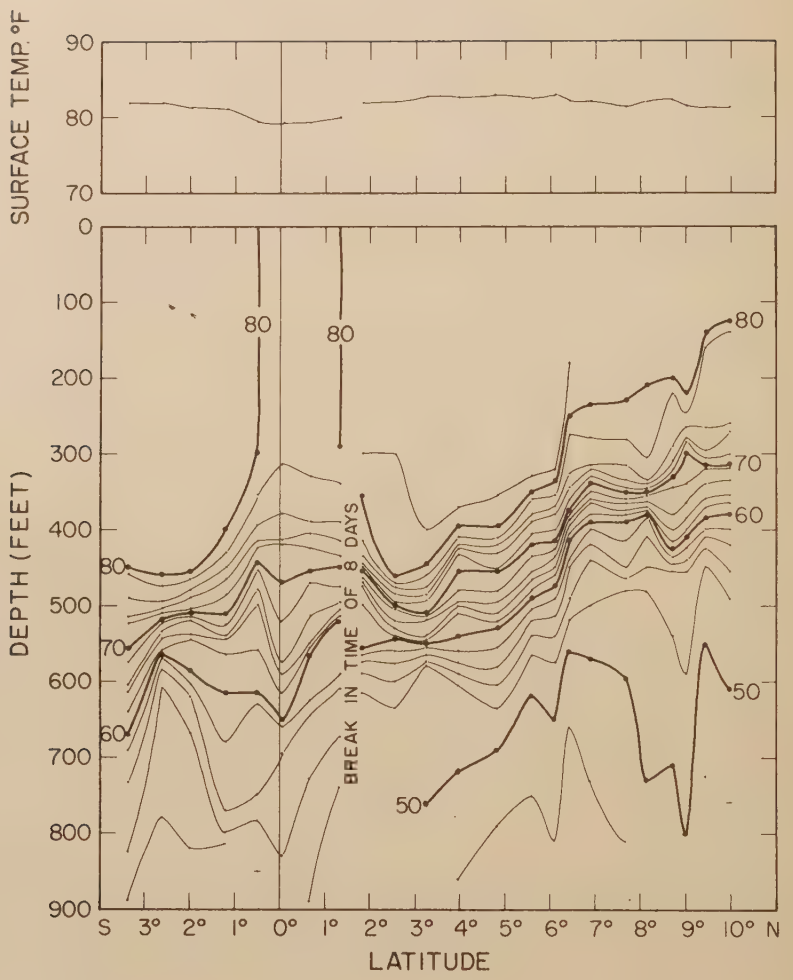

Figure 17.--Surface temperatures and vertical temperature section along 155°W. longitude, August 1953 (Manning cruise 16). Upper panel--surface temperatures as read at each bathythermograph lowering. Lower panel--temperature section based on bathythermograph lowerings; isotherms at 2°F. intervals, depth of lowering shown by small horizontal dashes.

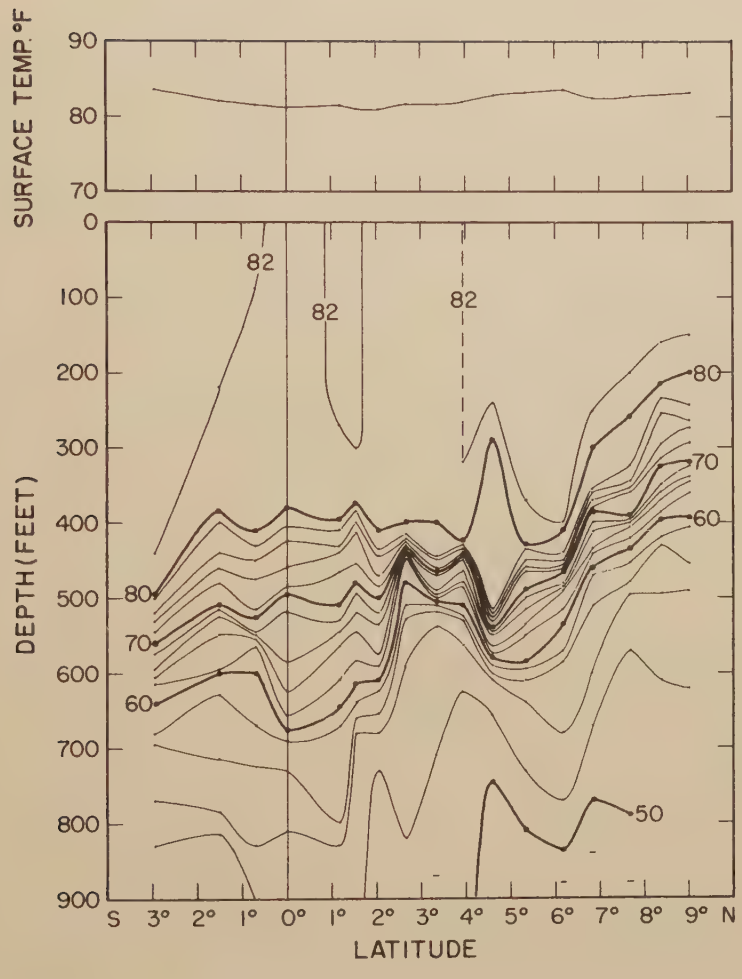

Figure 18.--Surface temperatures and vertical temperature section along 160°W. longitude, August 1953 (Manning cruise 16). Upper panel--surface temperatures as read at each bathythermograph lowering. Lower panel--temperature section based on bathythermograph lowerings; isotherms at 2°F. intervals, depth of lowering shown by small horizontal dashes.

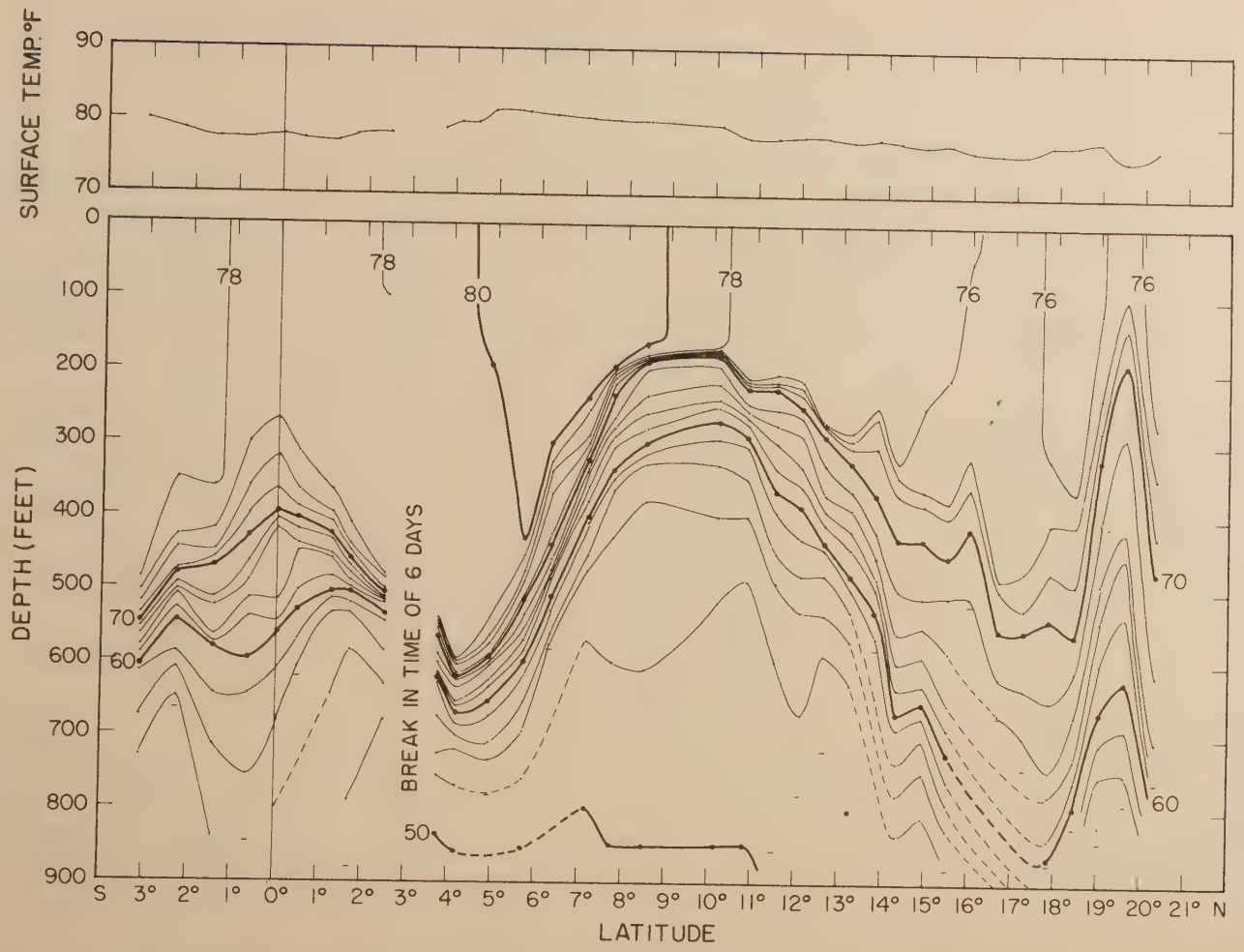

Figure 19.--Surface temperatures and vertical temperature section along 155°W. longitude, December 1953 (Manning cruise 18). Upper panel--surface temperatures as read at each bathythermograph lowering. Lower panel--temperature section based on bathythermograph lowerings; isotherms at 2°F. intervals

REACTION OF TUNAS TO STIMULI, 1952-53

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FISH AND WILDLIFE SERVICE

Explanatory Note

The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

REACTION OF TUNA TO STIMULI, 1952-53

Part I: Response of tuna to chemical stimuli, by Albert L. Tester, P. B. van Weel, and John J. Naughton

Part II: Response of tuna to visual and visual-chemical stimuli, by Sidney C. Hsiao and Albert L. Tester

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Frontispiece--Tuna Study Pond at Coconut Island, Oahu

PART I

RESPONSE OF TUNA TO CHEMICAL STIMULI

BY

Albert L. Tester, P. B. van Weel, and
John J. Naughton
University of Hawaii

In 1951, exploratory studies of the response of tuna and other fish to chemical, visual, auditory, and electrical stimuli were conducted by P. B. van Weel, S. C. Hsiao, I. Miyake, and A. L. Tester (Special Scientific Report: Fisheries No. 91) of the faculty of the University of Hawaii under contract (No. I6fw-13331) with the U. S. Department of the Interior, Fish and Wildlife Service, Pacific Oceanic Fishery Investigations. It was hoped that these studies not only would contribute to an understanding of tuna behavior but also would provide an indication of ways of attracting tuna to within the reach of a fishing vessel at sea.

Of the various 1951 studies, the most promising was in the field of chemoreception. Van Weel (1952) found that little tunny (Euthynnus yaito) and yellowfin (Neothunnus macropterus) held in captivity responded to clear, almost colorless extracts of tuna flesh.

A new 1-year contract (No. I6fw-18564) for a further study of the reactions of tuna to chemical stimuli became effective June 1, 1952. Efforts were to be made to duplicate and extend van Weel's observations, to identify chemically the attractive substance(s), and to make observations on the reaction of the fish to combined chemical and visual stimuli.

This report deals with the 1952-53 results in the field of chemoreception and includes a brief account of the success attained in fishing and establishing the tunas in captivity.

Note: Contribution No. 47 of the Hawaii Marine Laboratory, University of Hawaii.

The tunas used in the study were caught and transported to Coconut Island by Mr. Lester Zukeran, skipper of the University of Hawaii research vessel Salpa. He was ably assisted by Mr. Stanley Kitagawa and Mr. Royden Ikeda, students at the University. In the ponds, the tunas were fed and otherwise cared for by Mr. Charles Nakamoto, assistant to the Hawaii Marine Laboratory, who also took water temperatures and samples of water for chlorinity determination.

At times, Mr. Austin Pritchard and Miss Shirley Trefz, graduate students in marine zoology, assisted in pond testing. Mr. Carl Swanholm, student in chemistry, assisted in preparing and analyzing test materials.

Samples of chemicals were provided gratis by E. I. DuPont de Nemours and Company through Mr. Raoul Pantaleoni, by Van Ameringen-Haebler, Inc., through Dr. Ernst T. Theimer, by P. R. Dreyer, Inc., through Mr. George H. Zirkel, and by Sindar Corporation through Mr. R. E. Horsey.

Mr. Fritz Jermann of Hawaiian Tuna Packers, Ltd., spent many hours preparing materials for testing and assisted in many other ways. Certain materials were also forwarded by Mr. Pete Sunderland of B. C. Packers, Ltd.

To all of these individuals, to the companies they represented, and to others who assisted in various ways we extend our sincere thanks. We are also indebted to Mr. O. E. Sette, Director, and other members of the staff of the Pacific Oceanic Fishery Investigations, U. S. Fish and Wildlife Service, for advice, assistance, and encouragement.

FISHING

As in the previous year (Tester 1952), tuna were caught by trolling with the 46-foot Salpa, using two lines suspended from each of two poles fastened to the mast amidships, and sometimes using one or two additional lines fastened to the stern. The ship operated three mornings a week off Kaneohe Bay during the period June 6 to August 31, 1952. As shown in table 1, the catch consisted of 63 skipjack (Katsuwonus pelamis), 66 kawakawa or little tunny (Euthynnus affinis), 1/ 33 yellowfin (Neothunnus macropterus), 6 dolphin (Coryphaenus hippurus), and 2 wahoo (Acanthocybium solandri). The catch per hour (all species) was low in June (1.70) but higher in

---

1/ Euthynnus yaito of previous reports (Tester 1952: van Weel 1952).

July (2.36) and August (2.40). The catch per hour for the three months (2.17) was less than that for the same three months in 1951 (3.20).

For tunny and yellowfin, the two species of tuna which we have established in captivity, the catch per hour was higher in 1952 (0.84 and 0.42) than in 1951 (0.40 and 0.31) for a comparable period. For skipjack, however, the catch per hour in 1952 (0.81) was considerably less than that in 1951 (1.48).

Fishing was not continued after August 1, 1952, (except for incidental trips) as the tank and pond were stocked with sufficient fish for our purposes.

Table 1.--The number of fish caught, fishing hours, and catch per hour for the 1952 fishing operations of the Salpa, with comparable data for 1951

Month	Number of fish caught							Fishing hours	Catch per hour
	Skipjack	Frigate Mackerel	Tunny	Yellowfin	Dolphin	Wahoo	Total		
June	21	--	8	6	5	--	40	23-1/2	1.70
July	29	--	29	19	--	2	79	33-1/2	2.36
August	13	--	29	8	1	--	51	21-1/4	2.40
Total, 1952	63	--	66	33	6	2	170	78-1/4	2.17
Total, '51 (June to August)	100	17	27	21	52	--	217	67-3/4	3.20

ESTABLISHMENT OF TUNAS IN CAPTIVITY

Profiting by last year's experience, attempts were made to establish only yellowfin and tunny in the concrete tank and in Pond No. 5, which were used successfully in 1951 (Tester 1952). The tank and pond are located on Coconut Island.

Concrete Tank

The concrete tank, which measures 35 x 11 x 4 feet and is supplied with running seawater by pumps, was modified slightly by rounding the corners with sheets of Masonite and painting the walls white. Despite these improvements only 2 out of 11 yellowfin

and 2 out of 13 tunny were established, the former but a short period of time.

Nine yellowfin (3 to 6 pounds) died within 1 or 2 days after introduction to the tank, without starting to feed. One, introduced on June 30 (4 pounds), started feeding on July 4 but was caught and stolen by poachers during the same evening. Another, introduced on July 14 (5-1/2 pounds), started feeding on July 22 but stopped on July 26. In obvious difficulty, it was removed from the tank on July 30 and was found to be blind, with bubbles in the eyeballs.

Eleven tunny (1 to 4 pounds) died within a few days after introduction to the tank. Of these, two started feeding but after 12 days became blind; one died and the other, in obvious difficulty, was removed from the tank. Two tunny, introduced respectively on June 16 and August 15, 1952, became established and lived throughout the winter. They were still alive on June 30, 1953. Both weighed about 1 pound when established and grew to about 4 pounds during the year 2/.

Pond No. 5

This pond, described in detail by Tester (1952), is about 360 feet long and 75 feet wide. The south side is shallow over its entire length, averaging about 3 feet in depth at high water. The north side includes a deep trough, which averages about 10 feet in depth. A slow circulation is effected by tidal action through screened gates at both ends. Both yellowfin and tunny were established in this pond in the summer of 1951 but died during the fall, following wet, stormy weather.

Between July 23 and August 27, 1952, 13 yellowfin (5 to 10 pounds) were placed in this pond. Of these, five started feeding and became established. Four of the 5 disappeared from the pond during the first 2 weeks in September--it is suspected that they were caught by poachers, although they may have died "naturally." In any

---

2/ One of these jumped from the tank and died on July 19, 1953. It was partially eaten (by rats or cats?) when discovered, and was not weighed. The other started ramming the walls of the tank and died on July 22, 1953. A film over the eyes indicated partial blindness, which may have contributed to its death when alone in the tank. It weighed 3-3/4 pounds at death.

event, the carcasses were not found. The fifth yellowfin died on September 16, 1952. An additional yellowfin (10 pounds) was placed in the pond on October 28, but it died 5 days later without starting to feed.

Of 15 tunny (1 to 1-1/2 pounds) introduced to Pond No. 5 between July 25 and August 25, 1952, 13 started to feed and became established, despite the fact that several were tagged (the tags later became detached). The remaining 2, which were tagged, died within 2 days. The 13 established tunny were present until October 16, 1952, following which 6 died--3 between October 16 and 20, 2 between October 21 and 27, and 1 between October 30 and 31. The remaining population of 7 fish was maintained until December 5, 1952, when 1 more died. The 6 remaining fish persisted until January 16, 1953. One died on January 16, 2 between January 17 and 20, and 1 between January 22 and 23, 1953. The 2 tunny which remained survived the winter and spring and are still living at the time of writing, more than 1 year after they were introduced. During this period they have increased in weight from about 1 to 4 pounds.

The reason for the mortalities of tunny reported above is uncertain. The temperature and chlorinity in Pond No. 5 are shown in figure 1. The six deaths in October coincided with the beginning of a steep downward trend in temperature and a slight downward trend in chlorinity, both of which were associated with the incidence of rainy weather. However, the four deaths in January cannot be related to changes in temperature and salinity. Moreover, the two remaining fish survived through February and March, when considerable rainy weather was encountered and when the chlorinity in the pond reached a low for the year (15.834 p.p.m. on March 11, 1953).

Although comparable temperature and chlorinity data for the previous year (when all fish died following wet stormy weather) are not available, in general, the winter weather in 1952-53 was much better than in 1951-52, with markedly fewer "kona" storms (south to southeast winds with rain). This may have contributed to the success in maintaining two of the fish throughout the winter. During the one bad storm of the 1952-53 season on October 13 and 14, mortality may have been reduced by tying the Salpa to the dock near the outer gates and flushing fresh water from the pond with the wash of the propeller.

Feeding

In both the tank and pond the tunas were fed during the late afternoon of Tuesday, Thursday, Saturday, and occasionally Sunday, of each week. Their food consisted mostly of tuna flesh

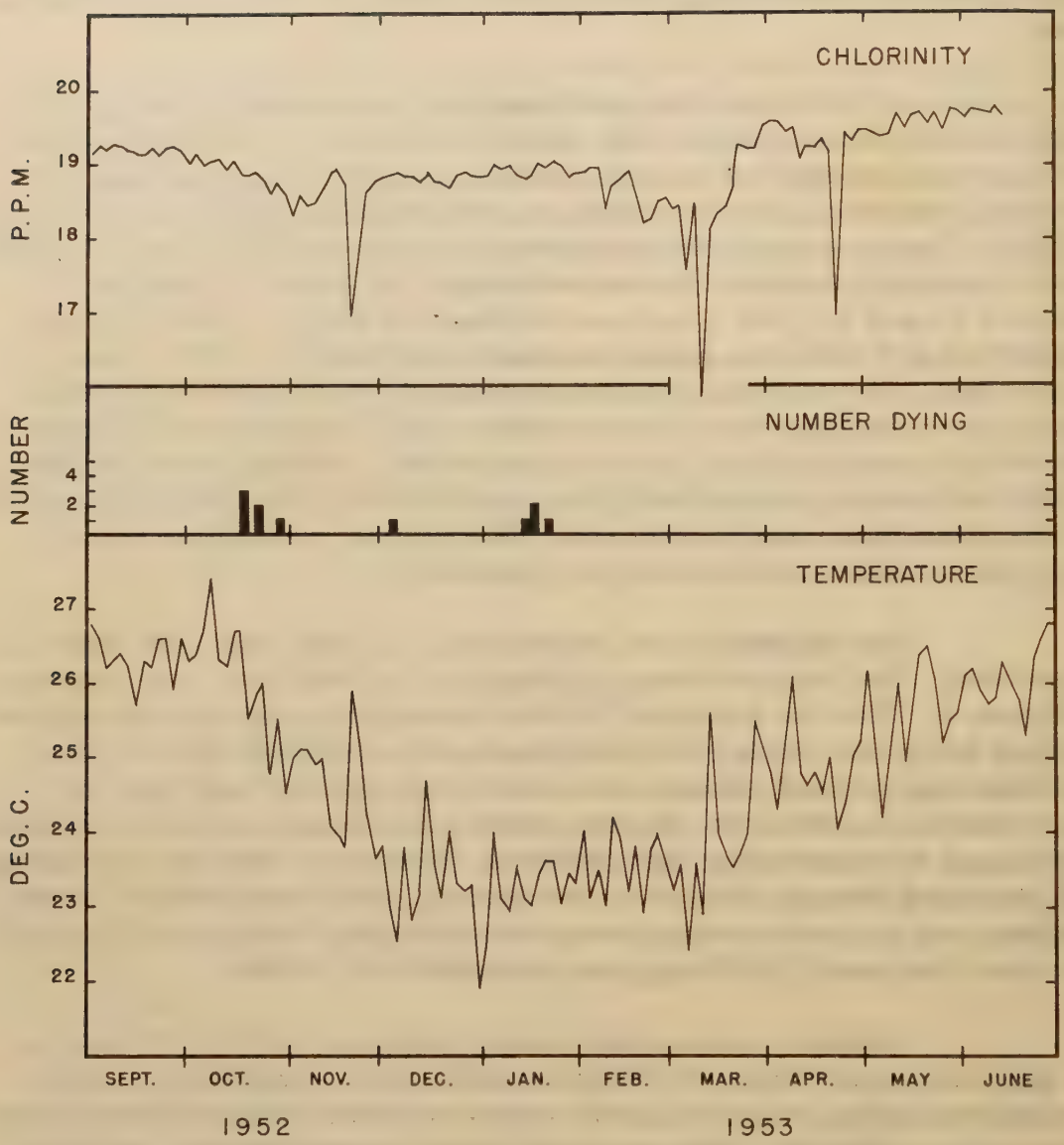

Fig. 1.--Temperature (^{o}C), chlorinity (p.p.m.), and mortality (number of fish dying) in Pond No. 5 over the period from September 1, 1952 to June 30, 1953.

(skipjack, yellowfin, or bigeye) or marlin--whichever was available--plus such other scrap fish as came to hand. In general they were fed at the rate of about one-half pound of food per fish per feeding, which is probably much less than their normal requirement. This schedule was maintained in order that the fish would be in a constant state of hunger on Tuesdays, Thursdays, and Saturdays when tests were usually conducted. Van Weel (1952) showed that this precaution was necessary.

Two departures from this diet are worthy of note. Firstly, the tunny established in the tank on June 16, 1952, was kept on a non-tuna diet, consisting of squid, anchovy, and other fish, until about the middle of July when certain tests had been completed. Secondly, following April 25, 1953, the two tunny in the pond were fed on imported (frozen) squid exclusively.

METHODS AND PROCEDURES IN TESTING

Concrete Tank

Tests were run in the concrete tank 2 or 3 times a week from July 1 to August 20, 1952, and occasionally thereafter throughout the remainder of the summer, the fall, and the winter. At first the methods were similar to those used by van Weel (1952). The observer stood by the railings at the side of the tank near the south end until the fish had become used to his presence and had resumed a steady slow circling. Several successive measurements and counts were made of (a) the time (in seconds) for 10 passes past the observer, with the fish swimming either up or down the length of the tank, and (b) the number out of 10 passes made in the half of the tank adjacent to the observer. Materials were then siphoned into the tank using a rubber hose, and the timing and counting were resumed. Excitement induced when the fish sensed the material was indicated by a decrease in the time of 10 passes (increase in rate of swimming) and attraction was indicated by an increase in the number of passes along the near side of the tank.

Often during attempts to establish control conditions the fish would remain excited for long periods of time by the presence of the observer, whom it could see; during both control and test periods it might also respond to the observer's movements while timing, introducing the materials, or recording the results. This difficulty was largely overcome on July 23, 1952, (following Test 13) by enclosing the upper railed section of the tank with tarpaper and building an observation booth (fig. 2). The three-ply front of the booth overhung the tank at its upper edge to increase the range of vision. It contained

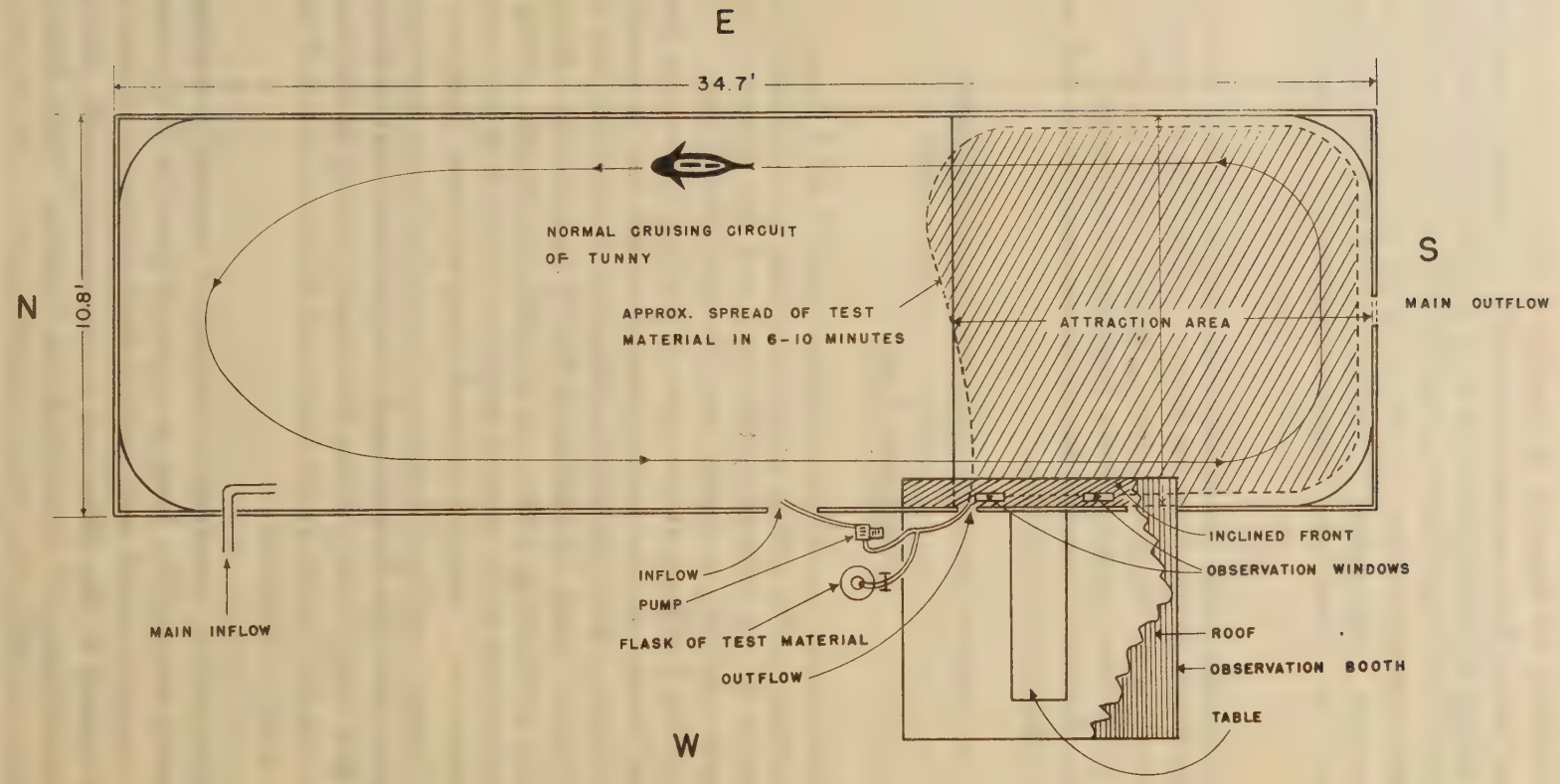

Fig. 2.--Diagram of the concrete tank showing the arrangement for introducing the test materials, the attraction area, and the observation booth.

two rectangular 6 x 10-inch observation windows the size of which could be varied to a narrow horizontal slit by means of sliding doors. Later, in August, the observation windows were equipped with one-way glass. As nearly as could be determined, the fish were generally unaware of the presence of the observer as long as strict silence was maintained. Occasionally, however, before the glass was used it seemed as if the fish were aware of the small part of the observer's face which was visible through the small slit-like aperture.

By means of a 3/8-inch centrifugal pump driven by a 1/30 h.p. near-silent electric motor, water was sucked from the surface of the tank at one side near the center and was injected into the southern or "downstream" one-third in a continuous stream during both control and test periods. When desired, the test material was introduced into this stream from within the booth through a glass T connection in the rubber tubing.

The method of measuring the reaction was modified from that of van Weel (1952). Each test consisted usually of five successive 2-minute control periods, followed by at least five successive 2-minute test periods. For each period, the time spent by the fish in the downstream one-third of the tank, marked off with string, was measured by an electric clock operated by a push switch, and the number of loops (half-circles) made by each fish in this "attraction" area was recorded on a hand counter. By means of fluorescein dye it was found that a liquid quickly spread throughout the downstream one-third of the tank, remained there for about 10 minutes, and then gradually dispersed up the tank along the far wall. If attracted by the material, the fish would be expected to spend a longer period of time in the attraction area as compared with control conditions. If excited by the material the fish would be expected to swim more rapidly and to circle more times in the attraction area than during control conditions. If a fish entered, turned, and left the area, the count would be one loop. If the fish entered, made a complete circle within the area, and then left, the count would be three loops. If two fish performed in this way, either together or independently, the counts would be doubled. Later the method of counting was modified to conform with that in the pond (see below).

The tests in the tank were conducted for the most part on one established tunny during the summer, and on two established tunny thereafter. Unestablished fish did not react to the test substances and were ignored in timing and counting. A typical series of reaction graphs is shown in figure 3.

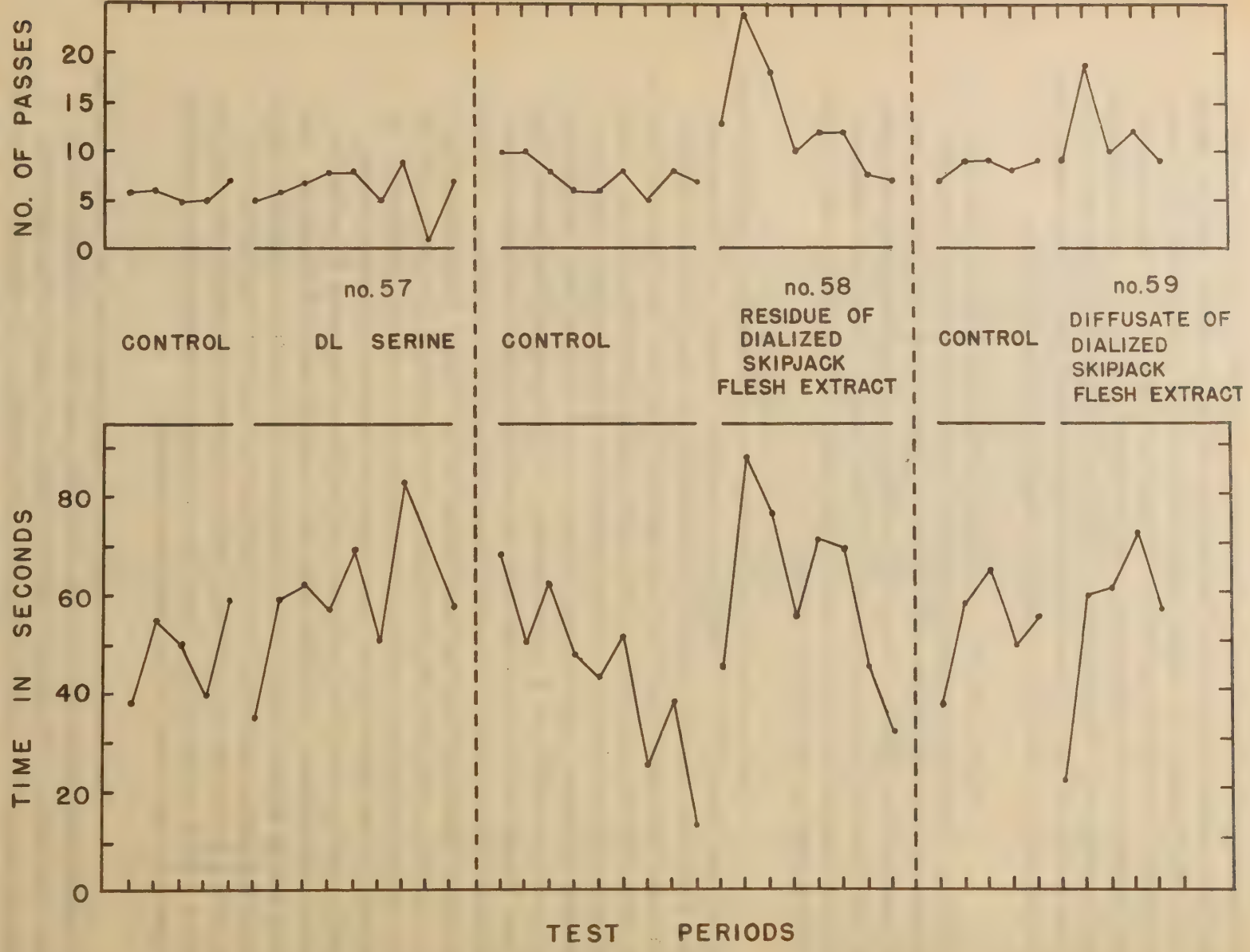

Fig. 3.--Number of passes and time (seconds) out of successive 2-minute periods for three tank experiments--Nos. 57, 58 and 59.

Pond No. 5

When weather and other conditions permitted, tests were run in Pond No. 5 two or three times a week, starting in August 1952 and continuing throughout the fall, winter, and spring. The general arrangement for testing is illustrated in figure 4.

By means of a 2-inch pump driven by a 3-h.p. electric motor, water was sucked from outside the "seaward" gates at the western end of the pond, led through a 2-1/2-inch rubber hose along the concrete gate supports to a point near the center of the deep trough in the pond, and then injected into the pond about 5 feet below the surface (from the high tide mark) through an L-shaped piece of 2-inch galvanized pipe. Test material was introduced into the flow through a funnel, the base of which was attached to a piece of 3/4-inch galvanized pipe by a rubber hose. The 3/4-inch pipe was brazed at an acute angle into a hole in the "down" section of the L-shaped pipe, creating a suction. The funnel was located within a small house erected above the seaward gates, thus effectively screening the operator when waiting to introduce test liquids.

The pump, which was rather noisy and which created a strong visible flow of water for about 20 feet into the pond, was kept running for some time before as well as during both control and test periods to accustom the fish to both the noise and the current. After tracing the path of the current with fluorescein dye, an "attraction" area was marked off with two pieces of cord stretched across the pond, one 39 feet and the other 78 feet from the seaward gates. The dye indicated that liquids introduced into the flow would reach the near edge of this area within about 1 minute, would spread throughout most of the area within about 3 or 4 minutes, and would for the most part remain in the area for an additional 10 minutes before appreciably dispersing downstream across the far cord.

To observe the fish, a wooden tower 20 feet high was built opposite the center of the attraction area on the north side of the pond. A platform and seat on top of the tower was reached by a ladder. As the material was introduced when the fish were starting to return from the far end of the pond, after pouring the material down the funnel the observer was able to move quickly from the small house to the tower, climb the ladder, and sit on the platform before the fish approached the attraction area. It is reasonably certain that he was not noticed by the fish either when moving to the platform or when seated on it. Timing and counting were conducted from the platform. Observation was improved by wearing polaroid sun glasses.

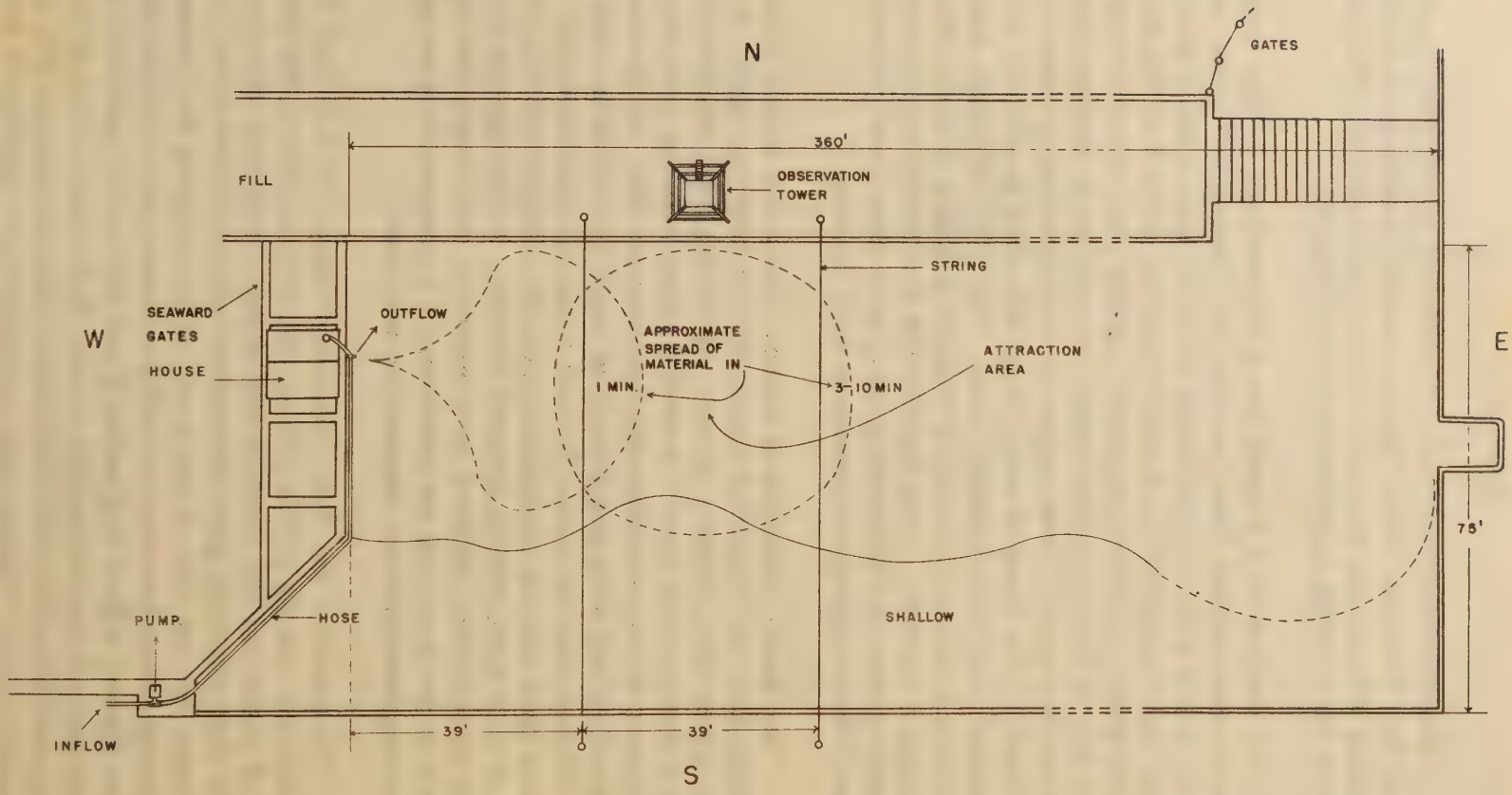

Fig. 4.--Diagram of Pond No. 5 showing the arrangement for introducing test materials, the attraction area, and the observation tower.

Each experiment usually included five 3-minute control periods and five 3-minute test periods. During each period the time spent by the tunny school or schools in the attraction area was measured on an electric clock operated by a push switch. The switch was depressed when the first fish of a school entered the area and was held down until the last fish left. A fish swimming by itself was ignored; often it was a partially-blind or otherwise incapacitated individual which was unable to keep pace with the others. In addition to timing the fish, each "pass" of each fish in either the upstream or downstream direction was recorded on a hand counter. Thus, if three fish swam through the area, the count would be 3. If they entered the area, looped, and left on the same side as they entered, the count would be 6. If they entered the area, described a complete circle within the area and then left on the opposite side to which they entered, the count would be 9. Time spent in the area was accumulated on the clock and the number of passes was accumulated on the counter. Both were recorded at the end of each 3-minute period. When the tunny population was large (6 to 13 fish), two observers were required on the tower, one of whom climbed down and introduced the test material between control and test periods, and returned when the fish were at the far end of the pond to avoid being seen. When the fish were excited during the early part of a reaction it was difficult to record all the movements, even with two observers; in some cases the counts were minimal estimates. As in the case of the tank, the difference between control and test periods in average time spent by the fish in the attraction area was used as a measure of attraction and the difference in count was used as a measure of the excitement induced by the test substance. A typical reaction graph is shown in figure 5.

In both tank and pond, in addition to the quantitative measure of reaction discussed above, the observer also indicated the strength of the response in one of several "observational" categories (- to XXXX). These will be discussed in a later section.

THE RESPONSE

A summary of data on 356 experiments which were conducted in the tank and pond at intervals over the period July 1, 1952, to May 19, 1953, is given in the appendix at the end of this report. The experiments will be referred to by number, e.g. Nos. 168, 170, etc. The results will be discussed in detail in later sections. For the present, attention will be directed at a description of a typical response in the tank and the pond.

When an attractive substance, such as an extract of tuna flesh, was introduced into the attraction area of the tank, the

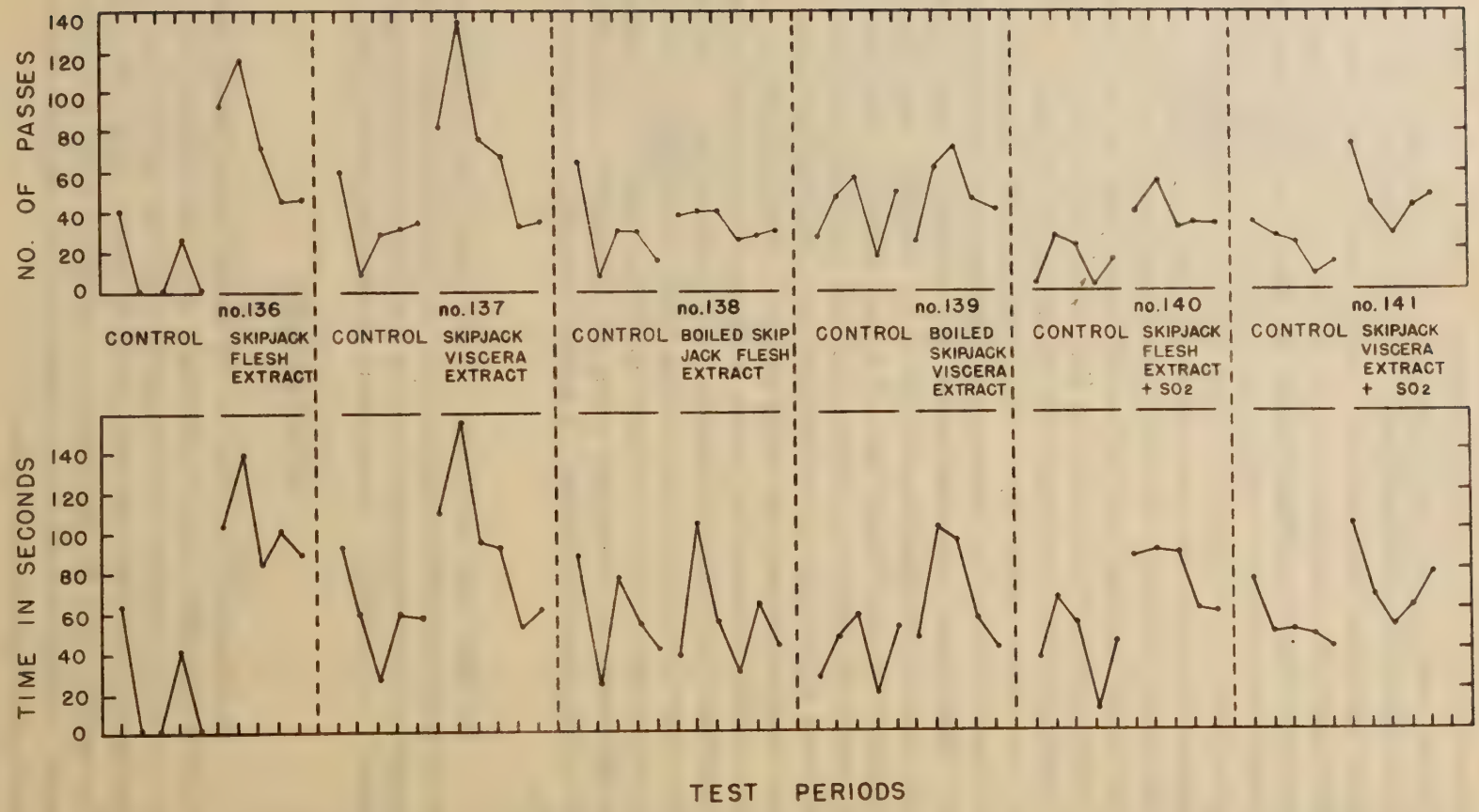

Fig. 5.--Number of passes and time (seconds) out of successive 3-minute periods in six pond experiments--Nos. 136 to 141, inclusive.

material was usually sensed by the tunny in its first pass into the area. Usually the fish would become excited immediately. It would increase its swimming rate, often quickly circling the tank. On returning to the area it would swim rapidly in small circles, splashing and swirling at the surface. At times the fish would flex its dorsal fin and snap with its mouth. Occasionally it would root uneaten food from the bottom and "play" with it (although not eating it as far as could be observed). This excitement would usually be pronounced in the first and second periods (4 minutes from start) but would gradually lessen, until after the fifth period (10 minutes from start) only a more rapid rate of swimming would be noted. If the reaction continued after the fifth period, it would usually take place outside of the attraction area along the far wall, where the material had been carried by the slow, counterclockwise current in the tank.

When an attractive substance was introduced into the pond, a reaction would take place immediately if the tunny happened to be near the point of injection. Usually, however, the material was introduced when the fish were starting to return from the upstream end of the pond. A reaction usually ensued during the first 3-minute period, as soon as the fish entered the attraction area. When several tunny were present, they would immediately depart from a linear, follow-the-leader type of schooling and fan out across the pond, darting into and out of the attraction area at or near the surface, frequently breaking the surface with their backs and creating a "bow wave" as they swam. Often individuals would make short circles in the area, splashing and biting at bubbles, dead leaves, or other objects which happened to be floating on the surface. This activity usually lasted for two periods (6 minutes from start) and often persisted with lessening tempo for five periods (15 minutes from start) or more. When darting into and out of the area, the point at which they turned back seemed to coincide roughly with the dispersion front of the material, the position of which could be inferred from experiments conducted with fluorescein dye. Usually the reaction was over within 15 minutes and normal swimming up and down the pond was resumed. Thus a typical strong reaction was indicated by (a) increased rate of swimming, (b) surfacing, (c) breaking up of usual school formation: a "fanning out" of the school, often followed by independent circling of individuals, (d) return to area after passing through the front of the substance, (e) feeding activity: splashing, lunging, and snapping at objects on the surface.

There was considerable variation in both the pattern and strength of the reaction. Sometimes the fish reacted to the material for but a short time within each period, in the meantime racing the entire length of the pond and quickly returning. When only two tunny

were present the reaction was similar to that described in the foregoing paragraph, but was less violent and less spectacular. Even with a larger number of fish, it could vary in its intensity from the very strong reaction described above to a slight sensing of the material - a mere swerving in the area as the fish passed through. Often only one or two (e.g. a and d above) of the five reaction components were evident. Also, of course, many of the substances which were tested gave no noticeable or measurable response.

PROBLEMS IN TESTING

From the foregoing account of the methods, procedures, and response one might assume that precise, clear-cut conclusions could be drawn from each test. This was not the case. There were several uncontrolled variables which affected the results and which made it difficult, and often impossible, to obtain reasonably consistent and comparable data.

Weather

In the tank, when the sky was overcast the fish were difficult to see and hence to time and count. Several experiments were conducted under unfavorable weather conditions, thus introducing an additional source of error in the quantitative data. Testing during rain squalls was usually avoided, for the rain rippled the surface and made observation very difficult. Occasionally, however, rain occurred while experiments were in progress, thus not only changing the conditions for observation of the fish during test as compared with control periods, but also providing a distraction which might affect the reaction of the fish.

These same difficulties were encountered to even a greater extent in the pond, where the water was deeper, and the fish were difficult to see from the tower when swimming deep. Occasionally, visibility was greatly reduced by southeast "kona" winds, which not only created a turbidity but also, blowing lengthwise down the pond, created ripples on the surface. Often, to avoid wasting a whole day, experiments were conducted under such conditions. Although the resulting data were not strictly comparable with those obtained during fair weather, a positive response during test periods could usually be detected as, when reacting, the fish tended to swim at the surface where they could be seen even under unfavorable weather conditions.

Power Failure

During a 2-week period in November 1952, and occasionally at other times, the power supply to the island and/or to the pumps failed. Rather than waste valuable testing time, pond experiments were conducted without the use of the pump. Test material was introduced by throwing it to the surface from the top of the tower when the fish were distant from the attraction area. It was noted that a material which was usually attractive to the fish was not sensed as soon as when introduced by the pump. Apparently it formed a layer on the surface under which the fish could swim without being aware of its presence. When it was finally sensed, it produced a reaction which was stronger than usual, probably because it was more concentrated than when introduced through the flow from the pump. Again, the data would not be strictly comparable with those obtained when the material was introduced in a normal fashion.

Erratic Behavior of the Fish

In the tank under ideal control conditions the fish would make full circles, keeping close to the walls and swimming at a steady rate. They would thus spend about one-third of their time in the attraction area and each would average about 3 or 4 loops in a 2-minute period. However, ideal control conditions were not often encountered. Usually experiments were run when inspection of the control data indicated fair regularity in movement and thus moderate variance in the data, even though the times and counts might differ considerably from the "ideal." At times, particularly when one tunny was the sole occupant of the tank, it would circle for long periods in either the upstream or downstream end of the tank, giving either zero or maximal times and counts. At times it would circle for several successive minutes at one end and would then repeat the performance at the other end. At other times it would swim back and forth along one wall, entering the attraction area either occasionally or not at all. When behavior patterns such as these were encountered, testing was usually abandoned, with consequent loss of time. Occasionally, in desperation, the material was introduced under such conditions, in the hope that the fish would sense it and show some response even though the data would not be comparable with those obtained with more nearly normal behavior. When two fish were present in the tank, even if one was not yet established, the pattern of movement was more uniform and usually yielded control conditions which did not depart excessively from the ideal.

In the pond, the large black yellowfin were more conspicuous and swam more slowly than the small blue-green tunny.

Although their reactions were noted, they were not measured because of the unsuitable swimming behavior. At times they would circle slowly for hours at one end of the pond; at other times they would circle for long periods at one end, move along one wall to the other end, and repeat the performance; only rarely would they move regularly up and down the length of the pond.

Under ideal control conditions, the tunny would swim up and down the pond in one or two schools at a leisurely but regular pace, occasionally pausing to circle or "play" for a few seconds at the ends. A trip down the pond and back usually required about 3 minutes. When joined by the yellowfin, sometimes the faster tunny and sometimes the slower yellowfin acted as pacemakers, thus varying the swimming speed. At times, either of their own volition or attracted by the yellowfin, the tunny would spend long periods of time, sometimes an hour or more, at one end of the pond. When this occurred, experiments could not be conducted for the test material might be diluted below the threshold for response before the fish entered the attraction area. Several experiments were spoiled when, following uniform control conditions and the introduction of the test substance, the fish failed to return to the area within the required time. Even if they entered the area for the first time during the second or third test period, the quantitative data would not be comparable with those obtained during normal behavior.

Measurement of Response

From the sources of variation discussed so far - weather, variation in testing procedure, and erratic behavior of the fish during either control or test conditions - the difficulty of obtaining consistent quantitative data will be apparent. Moreover, the timing and counting did not measure the more obvious characteristics of a complex positive reaction - surfacing, splashing, and feeding activity. On one occasion the response was recorded on motion picture film, a method which might lead to a better quantitative measure. However, this method was not feasible in regular testing because of the great variation in visibility of the fish (depending on weather, turbidity of the water, height of the tide, and depth of swimming of the fish) and also because of the prohibitive cost of the thousands of feet of film that would be necessary to record the many experiments which were conducted.

A series of pond experiments (Nos. 94 to 100, inclusive) has been chosen to illustrate the nature of the data and the problems of statistical analysis and interpretation under average conditions of observation and behavior of the fish. These seven experiments were undertaken in succession throughout the day of August 26, 1952, four

in the morning and three in the afternoon. The sky was overcast, with a few rain squalls in the morning. Twelve tunny and four yellowfin were present, but only the former were timed and counted. The nature of the test substances is not pertinent to this discussion.

The basic data are shown graphically in figure 6.

It will be noted immediately that there is a high correlation between the times and number of passes for successive test periods ($r = 0.874$; P less than 0.01). Both variates reflect the reactions almost equally well in this particular series. It will also be noted that in all experiments except No. 98, the times and counts during the test periods are generally higher than during the preceding control periods.

Analysis of variance was employed to determine if there were significant differences between the means of control and test periods (equivalent to a "t" test) for each separate experiment. The results are shown in table 2. It may be concluded that there is a statistically significant response to the test substances of experiments Nos. 95, 97, 99, and 100 (P less than 0.05 or 0.01).

In experiment No. 98 the average time and count during the test periods were both slightly less than during the preceding control periods. Obviously, however, this was due to unusual activity during the controls. To overcome this difficulty a more informative method of analyzing the data is to group all control periods for all experiments as T_0, determine the mean square between means for experiment T_0 to T_7, determine the pooled mean square within experiments, and use this last to determine a least significant difference (fiducial interval) of a treatment mean for comparing not only T_1 with T_0, T_2 with T_0, etc., but also for comparing T_1 with T_2, etc. The analysis, for time data only, is as follows:

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Between treatments	7	16,157	2,308	5.0**
Individual periods	62	28,671	462	

** P less than 0.01

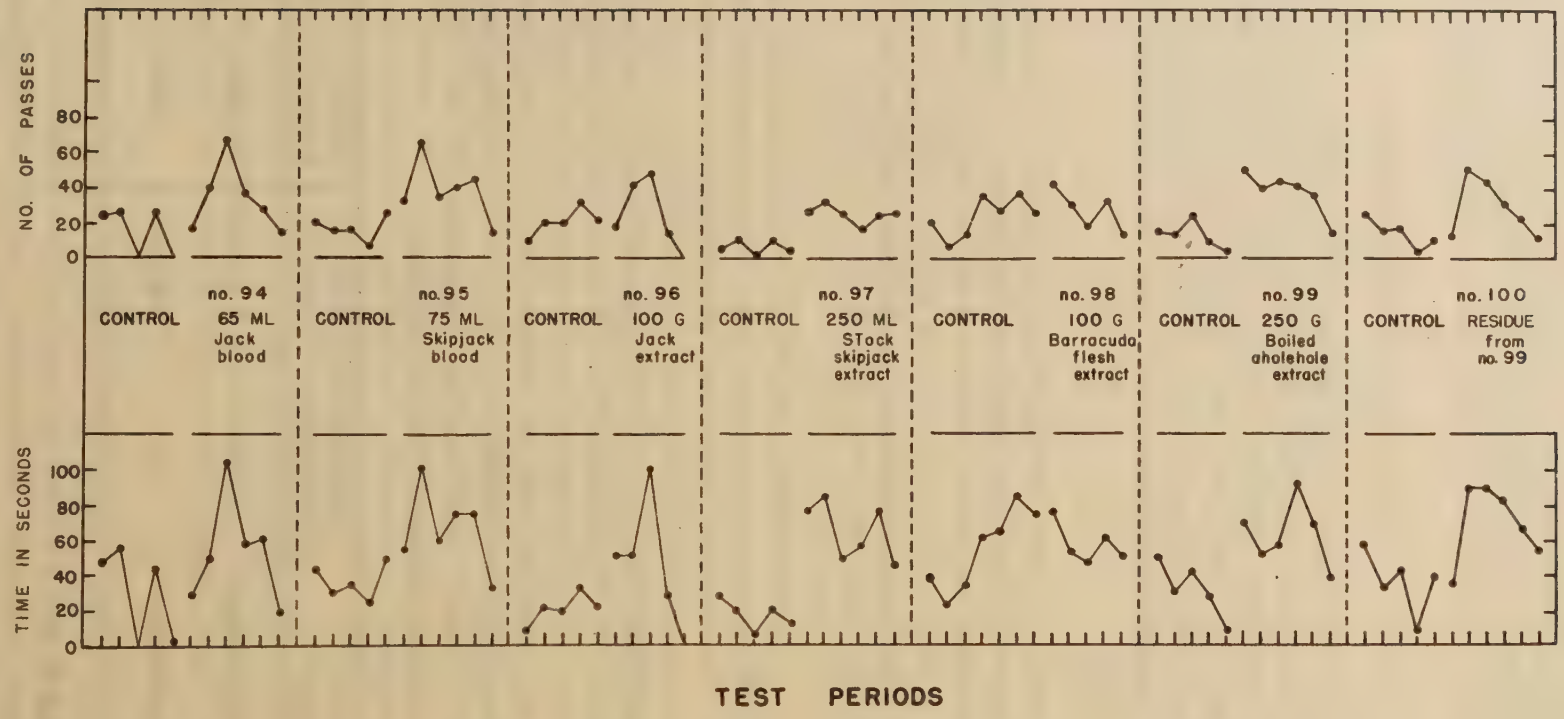

Fig. 6.--Number of passes and time (seconds) out of successive 3-minute periods in seven pond experiments--Nos. 94 to 100, inclusive.

The fiducial interval of a treatment mean may be calculated as follows (Snedecor 1948: p. 221):

$$\pm t_{.05}\sqrt{\frac{s^2}{k_o}}$$

$$= \pm 2.0\sqrt{\frac{462}{7.14}}$$

$$= \pm 16$$

The mean for the controls is 36.2 seconds; those for the experiments are included in table 2. Again, the means for only four experiments, Nos. 95, 97, 99, and 100, as before, differ significantly (by 32 seconds or more) from the mean for the controls. There are no significant differences between the means for any of the seven experiments. This latter conclusion is also evident from a further analysis of the variance of the combined results:

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Treatment vs. control	1	13,138	13,138	28.2**
Treatment means	6	3,019	503	1.1
Individual periods	62	28,671	462	

The above analysis, based on quantitative data, has demonstrated a significant response in four of the seven experiments. Observation, however, showed a response in all seven, namely, obvious sensing of the material combined with one or more of the several components of the reaction, as described previously. Only in No. 98 was there any doubt; even here, however, there was an obvious change in pace and surfacing of the fish during the first and second test periods. The data and their analyses do not always reflect a response which is obvious and "significant" to the observer. Other experiments could be selected in which the discrepancies between the data and the observations are even more pronounced.

The difficulties outlined above were recognized early. Nevertheless timing and counting were continued: they did measure certain phases of the reaction and have been used in some quantitative

Table 2.--Data on a series of seven experiments (Nos. 94 to 100, inclusive) conducted on August 26, 1952, in Pond No. 5.

Experiment No.	Control means		Test means		Difference		F		Sum of time and count differences	Observed response
	Time	Count	Time	Count	Time	Count	Time	Count		
94	30.8	15.8	60.6	37.8	30.6	22.0	3.2	4.6	52.6	X
95	36.6	17.6	73.0	44.0	36.4	26.4	13.1**	15.5**	62.8	XX
96	38.4	20.8	45.4	24.2	7.0	3.4	0.1	0.1	10.4	X
97	17.6	5.8	68.0	25.0	50.4	19.2	43.0**	42.7**	69.6	XX
98	63.8	27.0	56.8	26.8	-7.0	-0.2	0.6	0.0	-7.2	(X)
99	21.8	13.4	68.2	42.4	46.4	29.0	13.7**	47.7**	75.4	XXX
100	36.0	14.6	73.0	32.4	37.0	17.8	8.0*	5.1*	54.8	XXX

* P less than 0.05 ($F_{.05}$ = 5.32; degrees of freedom = 1 and 8)

** P less than 0.01 ($F_{.01}$ = 11.26; degrees of freedom = 1 and 8)

comparisons; in addition they assisted in maintaining standard tests. Generally, however, reliance was placed on the observer's judgement of a response as gained from visual observation. At the close of each experiment, the strength of a response was recorded in one of several categories (or a fraction thereof) which are designated as follows:

Designation	Numerical equivalent	Description
0	0	No noticeable response.
(X)	0.5	An apparent sensing of the material; of doubtful biological significance.
X	1	A weak but positive response, usually including few of the components (surfacing, speeding, etc.)
XX	2	A moderate positive response, including most components.
XXX	3	A strong positive response, including all components.
XXXX	4	A very strong positive response, including all components; great excitement.

Often a reaction would be indicated by X(X) or XX(X), with numerical equivalents of 1-1/2 and 2-1/2 respectively.

Although admittedly subjective and not well-suited to statistical analysis, the foregoing measure is simpler and at times more meaningful than that dependent on the timing and counting alone. The two observers, by working together, attempted to standardize their judgement of the strength of a reaction. The observed reactions, measured in the above categories, are included in table 2 for the series of experiments analyzed in the preceding paragraphs. They may be compared with the summed time and count differences in the second to last column of the table. There is general agreement between the two measures in that the stronger observed reactions (XX and XXX) are associated with the greater differences between control and test quantitative data. However, there are also notable discrepancies as, for example, in comparing

No. 94 and No. 96: although the observed reaction is judged the same, X, the quantitative data diverge widely (although not significantly according to statistical tests). As will be indicated later, the observer's judgement of the strength of a reaction tended to change with time and with decreased reactivity of the fish. Thus a reaction which might be classed as X in August would likely be classed as XX or XXX in April.

Variation in Response

The strength of the response to an attractive substance, whether measured by the quantitative data or estimated by visual observation, varied greatly from test to test both within and between days. Throughout the mass of data there are numerous examples of this. For example in experiments Nos. 67, 72, 80, 97, 106, 111, 117, and 173, which were all conducted by one observer using the same material (250 ml. stock extract), the response varied from 1 to 3 (X to XXX) on the observational scale.

At times it was suspected that the variation in response was associated with either the frequency of testing or the accumulation of test products. These factors could readily influence the results obtained with fish in the tank, for it had both a small volume and a small rate of flow of salt water. Thus, following four experiments in which relatively large quantities of test substances were used (Nos. 59 to 62), there was no response to a relatively large volume (1,000 ml.) of stock extract (No. 63) in the fifth experiment of the day. After a rest period of 3 days in which no tests were conducted, much smaller volumes (250 ml.) of stock extract gave strong responses (Nos. 81 and 82). In the pond, at times there appeared to be a gradual increase in activity under control conditions and a gradual decrease in response to attractive substances when several experiments were conducted in succession during a day (fig. 5). This may be attributed to several possible causes including chance or random variation, an increasing concentration of materials in the pond, or an increasing threshold of response under repeated stimulation. When a response was protracted beyond the ordinary time limit, usually the observer would wait for 15 to 30 minutes before starting the next experiment to allow the fish to resume normal control activity. To some extent this would overcome the trends which are noted above.

In April 1953 a series of experiments (No. 313 et seq.) was undertaken to determine if there were differences in response to materials maintained at three different hydrogen ion concentrations (T_1--pH 2, T_2--pH 7, T_3--pH 10), but also to investigate

the variation in response within and between days. Both the experimental plan and the observational data are included in table 3. Two tunny were present in the pond throughout the 3-week period. Various difficulties were experienced which prevented the completion of all experiments in the series--either erratic behavior of the fish or other difficulties as listed in the footnotes to table 3.

The great variation in response is apparent from the data of table 3. For T_1 and T_2 it ranged from 1/2 to 4, and for T_3 from 1/2 to 2-1/2. A superficial analysis of that portion of the data comprising complete blocks (a.m. only) showed that none of the main effects (order of testing, days, and treatments) was significant. Order of testing contributed the largest mean square, days the next largest, and treatment the smallest. The last was less than the residual mean square. In these and other series of experiments often it has been noted that the first experiment of the day gives the strongest response: the fish are suddenly aroused from a quiescent condition and give a strong response relative to both the preceding control periods and the succeeding test periods. This contributes to the variation between means for order of testing (respectively 2.4, 1.3, and 1.3 for the observational data above). Variation in reactivity from day to day, apart from erratic behavior, has been noted repeatedly by both observers, and is believed real despite the non-significance of the data above. The reason is obscure--it is unlikely that it is related to the state of hunger of the fish; it has been suspected at times that it is related to the weather, tides, or turbidity, but these factors cannot be adequately investigated with the present data.

There seemed to be a decrease in the response and an increase in its variability between the summer of 1952 and the spring of 1953. Thus, in six pond experiments conducted with the same material (each equivalent to about 25 g. of tuna flesh) during August, the mean difference between timing for test and control periods was 32.6 seconds and the range was 11.2 to 52.2 seconds. In the test series conducted in April, in which the material was equivalent to about 350 g. of tuna flesh (14 times as much as before) treated in a different manner but one which did not significantly decrease its attractive properties, the mean difference between the timing for test and control periods was 7.1 seconds with a range of -13.0 to 61.8 seconds. The decreased response was reflected to only a slight extent in the observational data which averaged 1.9 for August and 1.7 for April; apparently there was a change in the observer's judgement of the absolute strength of a reaction. The reason for the decrease in response and the increase in its variability may be related to a decrease in the pond population from 13 to

Table 3.--Observational data on a series of experiments (No. 313, et seq.) conducted during April 1953 in Pond No. 5 (T_1--pH 2, T_2--pH 7, T_3--pH 10).

Week	Date	Observer	Treatment-Response						Mean
			Order - a.m.			Order - p.m.			
			1	2	3	1	2	3	
1	4/9	Tester	T_1--4	T_2--2	T_3--2	T_1--2	T_2--2	T_3--1	2.2
	4/11	van Weel	T_1--2-1/2	T_2--1	T_3--1/2	T_1--1-1/2	T_2--1/	T_3--1/	1.4
2	4/14	Tester	T_3--1-1/2	T_1--1	T_2--1	T_3--1	T_1--1/2	T_2--1/2	0.9
	4/18	van Weel	T_3--1/2	T_1--1	T_2--2-1/2	T_3--2/	T_1--1	T_2--1-1/2	1.3
3	4/21	Tester	T_2--2	T_3--3/	T_1--3/	T_2--3/	T_3--1/2	T_1--3	1.8
	4/25	van Weel	T_2--3-1/2	T_3--1-1/2	T_1--1/2	T_2--4	T_3--2-1/2	T_1--2-1/2	2.4

1/ Material lost because of leak in hose.

2/ Fish did not enter attraction area during test periods.

3/ Material not used; fish remained at one end of pond.

2 tunny. This decrease in the number of fish would, of course, decrease the absolute values of the quantitative data, particularly the counts, but it would not necessarily change the difference between control and test data. Apparently 13 fish gave a much greater response than 2 fish to the same amount of material, suggesting a "group" effect--a contagious excitement. On the other hand, the decrease in response may have been related to decrease in the "condition" of the fish and a declining interest in food substances during the winter months.

SOURCE AND PREPARATION OF TEST SUBSTANCES

Materials

The materials which were used are listed for each experiment in the appendix at the end of this report.

Because of its ready availability and also because it had given a positive response in experiments conducted by van Weel (1952), most of the preparations consisted of extracts of tuna flesh, including skipjack, tunny, yellowfin, and bigeye. In addition, extracts of tuna skin, blood, liver, ovaries, testes, and unsegregated viscera were used.

A few tests were conducted with extracts prepared from "white-fleshed" fish (as opposed to the red-fleshed tunas) when materials were available. They included "aholehole" (Kuhlia sandvicensis) flesh, jack (Caranx) flesh and blood, barracuda (Sphyraena barracuda) flesh, and wahoo (Acanthocybium solandri) flesh.

The tuna and other fish used in these preparations were either fresh-caught or fresh-frozen. They were obtained from our own fishing operations, from the Pacific Oceanic Fishery Investigations, or from the Hawaiian Tuna Packers, Ltd.

Beef blood obtained from a local slaughter house was used in comparison with fish blood.

Tuna cannery byproducts, including fish meal, stick-water (effluent), and various preserved digests of skipjack viscera made for other purposes by Mr. F. Jermann of Hawaiian Tuna Packers, Ltd., were tested. A herring reduction plant byproduct, "condensed herring solubles" prepared by B. C. Packers, Ltd., Vancouver, Canada, was also used.

As time permitted, tests were run on a variety of organic chemicals purchased from Nutritional Biochemicals Corporation and Eastman Kodak Company. A variety of aromatics used in perfume manufacture and food flavoring were supplied by courtesy of E. I. DuPont de Nemours and Company, Van Ameringen-Haebler, Inc., P. R. Dreyer, Inc., and Sindar Corporation. Miscellaneous substances which were tested included alleged commercial fish attractants and pineapple juice.

Preparation

It is not feasible to describe in detail the method of preparation of each substance which was tested. This has been summarized for each experiment and has been included in the appendix. General techniques and procedures, only, will be discussed here. Where necessary, details of special preparations will be included in later sections.

Simple extracts of fish flesh, skin, gonads, liver, etc. were prepared as follows: a quantity of material (usually about 100 g.) was weighed, cut into small pieces, placed in a Waring blendor with about 200 ml. of sea or tap water per 100 g. of material, and reduced to a homogeneous suspension of finely-divided particles over a 5-minute period. The material was then diluted to about 1 liter with water and was placed in a refrigerator (at about 1° or 2° C.) for several hours. The mixture would be used as such, or it would be separated into liquid and solid components by either filtering or centrifuging before testing.

A "stock extract" of skipjack flesh was prepared in bulk by grinding 9 pounds of flesh in a meat grinder, placing this in a milk can of 10 gallons capacity, adding tap or sea water to nearly fill the can, and placing the can and contents in the refrigerator. The solid material would settle from the liquid in a few hours. The clear, amber to cherry-red liquid (the exact color depending on the proportion of light to dark red meat in the sample) could be decanted from the surface. It was calculated that 1 liter of liquid contained the extract from about 100 g. of flesh. The stock extract could be maintained without putrefaction for 2 or 3 weeks in the refrigerator if the temperature was held just at or above the freezing point. The stock extract was used frequently as a standard in testing other substances.

In most of the experiments conducted during the winter and spring, 95-percent ethyl alcohol was used in the preliminary extraction of ground tuna flesh. The alcohol extract was amber to

cherry-red in color as in the case of the water extract. Alcohol served as both an extracting and a preserving agent; refrigeration of the extract was not necessary, although it was used occasionally.

More complex procedures were used in attempts to isolate and identify the attractive substance(s) in extracts of tuna flesh and viscera. These included fractionation of the extract into two or several components to determine, on pond testing, which still retained the attractive properties. In some preparations, a first separation into "protein" and "non-protein" factions was achieved by precipitation of the proteins and similar complex substances. Precipitation was accomplished in various ways, e.g., heating, boiling, saturation with sodium chloride or "salting out", adding tannic and/or phosphotungstic acid, adding the salts of heavy metals such as lead, barium, etc., as well as adding other chemicals to remove those used in precipitation. In other preparations the extract was separated into two fractions by dialysis to determine whether the attractant was comprised of a small molecule which would pass through a dialyzing membrane, or a large molecule which would not pass through a membrane. In still others the extract was divided into a "fatty" and a "non-fatty" fraction, and each was tested in the pond to determine if the attractant was a "fatty" or a "non-fatty" substance. Fractionation was accomplished by removing the fatty acids and similar compounds by extraction with petroleum ether and/or acetone. Other procedures were aimed at determining whether the attractive substance consisted of a positive or negative ion. In these, fractionation was achieved by passing the extract through anion and/or cation exchange resin columns giving two portions, that adsorbed by the column (subsequently removed by elution or washing) and that not adsorbed by the column (the filtrate). In addition, columns of activated charcoal and activated alumina were used to see if they would adsorb the attractive substance.

In many of the preparations, several of the foregoing fractionation procedures were used in succession, each successive portion being tested and being either accepted or rejected for further fractionation depending on whether pond tests indicated that it did or did not include the attractive substance. Several of the procedures were used even though they did not remove the attractive substance; they did remove non-active substances and thus constituted a step in the purification of the attractant. The attractant, when purified as completely as possible by the successive removal of non-attractive substances, was then subject to basic chemical tests in an attempt to determine its basic components and chemical structure.

Miscellaneous chemical compounds were prepared for testing by dissolving in tap water or in weak alcohol solutions, or in

the case of fatty or oily substances, by dispersing in water with a dispersing agent "Tergitol". If the latter was not effective, the mixture was forced through an emulsifying apparatus to insure its complete dispersion.

RESPONSE TO SIMPLE EXTRACTS OF TUNA AND OTHER FISH

Flesh Extracts of Tuna

There are many experiments to show that in both the tank and the pond the tunny (and to a lesser extent, the yellowfin) gave a positive response to clear, aqueous extracts of skipjack flesh (Nos. 1, 8, 10, 13, 20, 50, 54, 64, 65, 66, 67, 72, 80, 81, 82, 87, 93, 97, 106, 111, 112, 117, 118, 122, 128, 135, 173, 199, 207), yellowfin flesh (Nos. 14, 18, 26), tunny flesh (No. 27) and bigeye flesh (Nos. 239, 252, 259). To these might be added a large number of experiments using either water or alcohol for extraction in which the materials were subjected to further treatment and which in many cases gave a positive response. In only a few experiments with simple extracts were negative results obtained when positive results were expected. In tank experiment No. 16, the fish had been fed 2 hours previously and were not responsive to skipjack flesh extract. In tank experiment No. 63 there was no response, due probably, as has been mentioned previously, to the dulling produced by an accumulation of test products in the tank with too frequent testing. In pond experiment No. 336, the fish failed to enter the attraction area during the 15-minute test period. In a few experiments, of course, the response was uncertain or slight (X).

The nature of the response to extracts of tuna flesh has already been described. It is a complex reaction, consisting primarily of an urge to feed, which is manifested by speeding, surfacing, circling, snapping at objects, together with a return to the area of stimulation.

It is presumed that in tuna flesh there is present a substance (or substances) which, when extracted and presented to the tunny, can be perceived through the fish's sense of smell or taste. The substance which, when smelled or tasted, promotes the urge to feed is henceforth called the "attractant." Unfortunately, as already pointed out, the response varies greatly in strength or manifestation between similar experiments. It appears to be influenced by many uncontrolled and perhaps uncontrollable factors.

One experiment (No. 112) is described in detail, for it differed from the others in method and purpose. Three liters of stock

extract was introduced into the pond, with the pump in operation, by slowly siphoning it into the funnel over a 48-minute period. This established a gradient of attractant from the outlet to beyond the attraction area. Timing, only, was attempted and this consisted of the time out of 3 minutes spent in the first 1/10th of the pond, i.e. the area between the seaward gates and the first string (fig. 4), not including the shallows. The results are shown in figure 7.

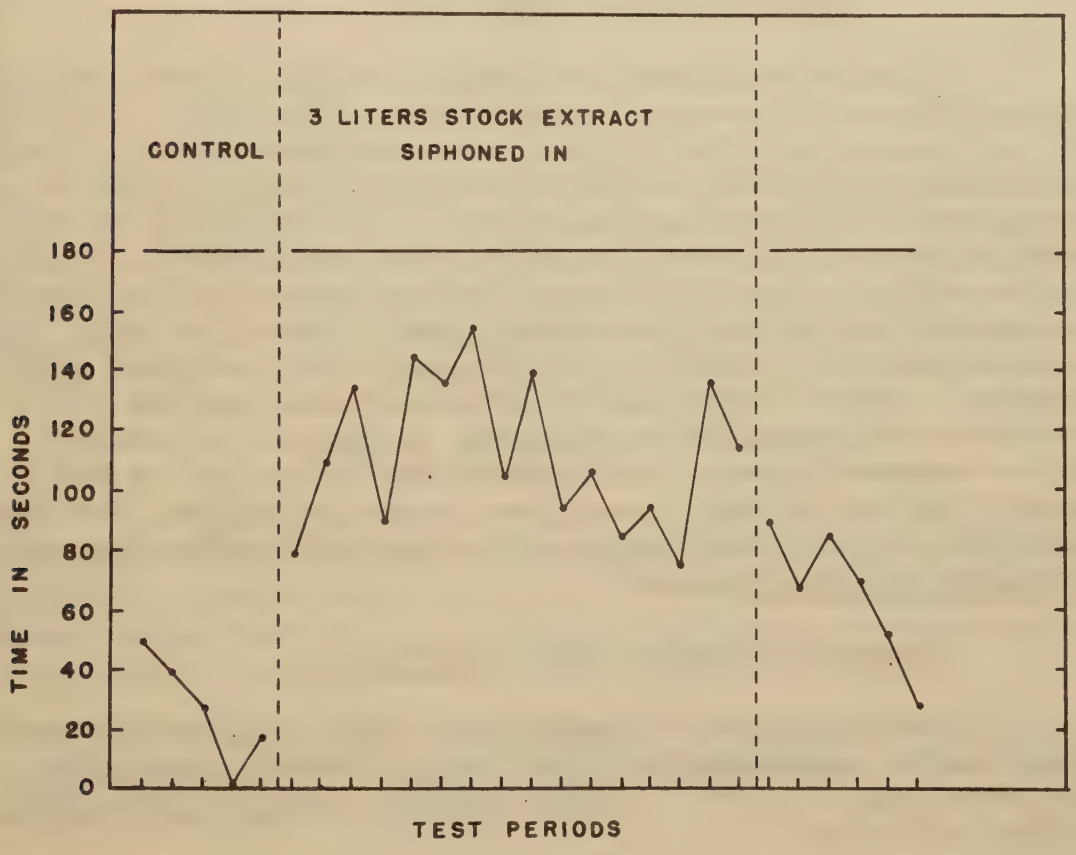

Fig. 7.--Time (seconds) out of successive 3-minute periods in pond experiment No. 112, in which a gradient of stock extract of skipjack flesh was established for 48 minutes.

The material was sensed very quickly by the tunny and produced a typical response, with all components, in the vicinity of the outlet. The response was maintained during the entire time necessary to siphon in the material. A few fish would leave the area and dash down the pond, but they would invariably return to the area of greatest concentration. After all the material had been siphoned in, the response quickly decreased until finally, after about 18 minutes, normal swimming was resumed.

Flesh Extracts of Other Fish

Positive responses were obtained not only to extracts of tuna flesh, but also to extracts of aholehole flesh (Nos. 49, 99, and 105), jack or ulua flesh (No. 96), and barracuda flesh (No. 98). There was no response to wahoo or ono flesh (No. 6), but the fish were not behaving well in this early tank experiment. It is evident that an attractant is present in at least some of the white-fleshed fish, as well as in the red-fleshed tuna. We gained the impression that the response was generally less in these flesh extracts than in those from tuna, but this cannot be proved because of the few experiments conducted with the former, variation in the quantity of material used, and the great variability in the strength of the response. In most of the comparisons the response appeared less (compare Nos. 49 and 50, 96 and 97, 97 and 98, 105 and 106) but in one it was greater (97 and 99). Van Weel (1952) obtained only a weak response to white-fleshed anchovy or nehu (Stolephorus purpureus) extract.

Extracts of Tissues Other than Flesh

Strong responses, ranging from XXXX to X, were obtained with extracts of unsegregated skipjack viscera treated in several different ways (Nos. 137, 139, 141, 145, 146, 219, 220, 221, 236, 264, 279, 352, 353, 356).

Excellent responses were also obtained with extracts of skipjack blood (Nos. 43, 70, 95), yellowfin blood (No. 23), and tunny blood (No. 30). Jack or ulua blood (No. 94) gave a positive though weaker response. In contrast to these results beef blood, either whole (Nos. 55 and 74) or the plasma portion (No. 61), was not attractive. In fact, whole beef blood, of a deep red color, was avoided by the tunny in both the tank and the pond experiments--a repellent effect which was probably visual in origin.

Excellent responses were obtained with extracts of yellowfin liver (No. 25) and tunny liver (No. 28).

Extracts of skipjack ovaries (No. 3) and yellowfin testes (Nos. 4, 17) were not attractive. However, whole extracts were used and the fish may have been frightened by the murky cloud which they produced in the water.

Unfiltered extracts of yellowfin skin (No. 24) and tunny skin (No. 29) also formed a dark cloud in the water and were more repellent than attractive. An almost clear centrifuged extract of skipjack skin (No. 48) gave a weak positive response.

It appears that the attractant is present not only in tuna flesh, but also in other parts of the fish. Again, however, it is difficult to come to any firm conclusion as to the relative strength of the response, and thus the relative concentration of the attractant in the various parts. In general the viscera extracts appeared to be at least as attractive as the flesh extracts, and possibly slightly more attractive. In two series of experiments designed to compare extracts of blood, liver, skin, and flesh (Nos. 23 to 26, Nos. 27 to 30), extracts of blood and liver appeared to be more attractive than extracts of flesh, and extracts of skin appeared to be less attractive.

Cannery Byproducts: Preservation

Good (XX) responses were obtained with extracts of tuna fish meal, both boiled (No. 119) and not boiled (No. 120) during extraction. Excellent responses (XXX) were obtained with tuna stickwater both by itself (No. 217) or mixed with fluorescein dye to trace its dispersion in the pond (No. 222).

"Condensed herring solubles," a product derived from the stickwater of a herring reduction plant (B. C. Packers, Ltd.) was not sensed by the fish (Nos. 328 and 329).

Several experiments were run on skipjack viscera preparations submitted by Hawaiian Tuna Packers, Ltd., with excellent results (XX to XXXX). In all preparations the viscera from the cannery were first ground in a meat grinder. In some they were preserved in 2- or 3-percent sulphur dioxide and self-digested, producing a particulate portion which settled to the bottom of the container and a supernatant dark brown liquid (Nos. 219, 221, 290, etc.). In others, the ground viscera were steamed at 20 pounds pressure and preserved in 3-percent phosphoric acid, again producing a solid and a supernatant yellow liquid (No. 220). A ground viscera preparation preserved in 2-percent sodium bisulphite and digested with pepsin gave little evidence of attraction in three tests (Nos. 258, 260, and 263). Apparently loss of attraction was due to something associated

with pepsin digestion rather than to the use of sodium bisulphite, for this preservative was used successfully in other preparations (Nos. 264, 279, etc.).

The above results, indicating that the attractive qualities are not lost when the materials are preserved in chemicals, are in accord with those obtained with our own preparations which were tested at an earlier date. Skipjack viscera extracted with water and treated with 2-percent sulphur dioxide (Nos. 140, 141), with 2-percent sulphuric acid (No. 144), or with 2-percent phosphoric acid (No. 145) were still attractive to the fish even after being kept at room temperature for several days.

RESPONSE TO CHEMICAL COMPOUNDS AND MISCELLANEOUS MATERIALS

As time permitted, a variety of chemical compounds ranging from amino acids to proteins and including vitamins and various miscellaneous aromatics were tested as follows:

Arginine (No. 32, 103)

l-Asparagine (No. 102)

Creatine (No. 109)

l-Glutamic acid (No. 191)

Glycyl-glycine (No. 127)

l-Histidine monohydrochloride (No. 192)

dl-Isoleucine (No. 34)

l-Leucine (No. 44)

Methionine (No. 157)

dl-Norleucine (No. 45)

dl-Phenylalanine (No. 31)

dl-Serine (Nos. 51, 56, 101, 104, 108)

l-Taurine (No. 42)

Acetyl tryptophane (No. 176)

l-Tyrosine (No. 33)

dl-Valine (No. 41)

Isoeugenol (No. 37)

Nucleic acid (No. 110)

Histamine diphosphate (No. 198)

Adenosine (No. 242)

Adenosine triphosphate, disodium salt (Nos. 243, 254, 271)

Adenosine diphosphate, barium salt (Nos. 245, 255, 270)

Adenylic acid (No. 244)

Trimethylamine oxide (No. 188)

Animal lecithin (No. 129)

Albumen (No. 62)

Peptone "I" (No. 189)

Vitamin B_{12} (No. 166)

Acetyl choline chloride (No. 192)

Pregnenolone (No. 132)

Ambergris (No. 131)

Anethol (Nos. 22, 71)

Phenyl acetic acid (No. 251)

Alpha ionone (No. 158)

Alamask (No. 172)

Furfuryl mercaptan (Nos. 231, 241)

Coumarin (No. 249)

Methyl anthranilate (No. 250)

Meat flavor (No. 253)

Pineapple juice (No. 168)

Eosin B (No. 36)

Methylene Blue (No. 38)

None of the above substances gave a positive response which could be verified. In some, however, there appeared to be a sensing of the substance as will be discussed below.

Among the amino acids, serine appeared to give a weak positive response in one tank experiment (No. 51) and a very weak positive response in another (No. 56). In three pond experiments, there appeared to be a sensing of the material in one (No. 101) but not in two others (Nos. 104 and 108). On the same day on which the fish appeared to sense the serine in the pond (No. 101) they also appeared to sense asparagine (No. 102) and arginine (No. 103), suggesting that they were in a particularly responsive condition. On another occasion they appeared to sense methionine (No. 157). Apparently the fish were aware of the presence of the substances but the slight reaction seemed to be one of curiosity rather than attraction: certainly it lacked the features of a typical response.

This same sensing of material was noted in the case of certain strong-smelling aromatics, e.g., anethol (No. 22), "meat flavor" (No. 253), and particularly furfuryl mercaptan (Nos. 231 and 241). The first substance, which has a licorice smell, is the active ingredient of oil of anise, a reputed fish attractant; the second is a strong, spicy, pleasant-smelling artificial flavor; the third is a very foul-smelling chemical of great potency. A similar response was noted with odorless vitamins, B_{12} (No. 166) and acetyl choline chloride (No. 192), and also with ordinary pineapple juice (No. 168). Again, however, the response seemed to be one of curiosity.

The series of experiments with adenosine, adenosine compounds, and adenylic acid was conducted in an attempt to determine if the attractive substance was one which is present in mammalian muscle. That it might be was suggested by chemical tests of the attractant (see later) which showed the presence of phosphorus and the amide

link. The substances were dissolved in sea water immediately before testing to avoid hydrolysis. The barium salt of adenylic diphosphate was dissolved in 0.1 N hydrochloric acid and the barium was precipitated with 6N sulphuric acid to have it present as free adenosine diphosphate acid, rather than as a barium salt (there had been indications that barium tended to destroy the attractive material). It was presumed that the pH of seawater would assure the proper molecular form of the sodium salt of adenosine triphosphate. First tests indicated a sensing and an attraction of the tunny to both adenosine triphosphate (No. 243) and diphosphate (No. 245) but not to adenosine (No. 242) nor to adenylic acid (No. 244). However, later tests with both the triphosphate (Nos. 254 and 271) and the diphosphate (Nos. 255 and 270) gave negative results.

The two dyes, eosin red (No. 36) and methylene blue (No. 38), were visually repellent to the fish. This same reaction, an avoidance, was occasionally noted with strong solutions of the greenish fluorescein.

In addition to the substances listed above, two alleged fish attractants were tested, one known as "Slik" which smelled of cod liver oil, and the other an unnamed "fish lure" which smelled of tuna or herring viscera extract. There was a slight sensing of the first (No. 174) and a weak but positive reaction to the second (No. 349).

ATTEMPTS AT ISOLATION AND IDENTIFICATION OF THE ATTRACTANT (S)

The attractant(s) was initially segregated from the flesh or other parts of the fish by virtue of its solubility in water. Thus, on centrifuging, the aqueous extract of finely-divided tuna flesh formed a clear amber to reddish colored solution which usually caused a strong positive response (Nos. 1, 8, 10, and numerous other experiments in both tank and pond). The residue from centrifuging was either attractive (No. 15) or not (No. 2), depending on either the thoroughness of the extraction or the part played by vision in the case of the murky mixture.

In early tank experiments, boiling of tuna flesh with water, thus precipitating the proteins and similar compounds, appeared to remove or destroy the attractant. The clear filtrate from the boiled flesh failed to elicit a response (Nos. 5, 9, 11, 12, 21) as was also found previously by van Weel (1952). However, as will be discussed later, this was not the case with boiled extract of flesh.

Dialysis, using a cellophane tube (1-5/8 inch diameter), was next tried in an attempt to segregate the attractant, using clear

aqueous extracts of skipjack flesh (several experiments) or tunny blood (one experiment). In all cases the dialyzate gave a positive response when tested (Nos. 39, 46, 53, 57, 90, 118, 123), showing that the attractant consists (in part, at least) of a small molecule, rather than a large molecule such as a protein. In no case, however, was complete separation attained by dialysis. In most of the experiments the residue (portion remaining in the tube) gave a stronger response than the dialyzate (compare Nos. 39 and 40; 52 and 53; 57 and 58; 90 and 91) despite several changes of the distilled water surrounding the tube.

Precipitation of the proteins by dilute (10-percent) hydrochloric acid was next attempted. After the centrifugate of an aqueous extract of skipjack flesh was treated with acid and centrifuged, both the neutralized centrifugate (No. 68) and the neutralized residue (No. 69) gave positive responses, showing incomplete separation of the attractant.

As the above results indicated that the attractant was not a protein, a series of pond experiments was undertaken in which the proteins were precipitated by heating. On heating the centrifuged aqueous extract of skipjack flesh to 69° C., a precipitate appeared. When this was removed by centrifuging, the centrifugate was still attractive (No. 76). When the centrifuged aqueous extract was boiled for 30 minutes, resulting in a heavy precipitate, both the filtrate in one experiment (No. 77) and the centrifugate in another (No. 78) were still attractive to the fish. However, separation was not complete, as is shown by the weaker positive responses obtained with the washed residue from centrifuging (compare Nos. 75 and 76; Nos. 78 and 79).

It is uncertain why the filtered extract of boiled tuna flesh failed to give a positive response in the earlier tank experiments Nos. 5, 9, 11, 12, and 21). Although the behavior of the fish in the tank was not too satisfactory, it seems certain that had a response occurred, it would have been noted or measured in one of the five experiments. It is unlikely that the attractant was destroyed by boiling in view of the results reported in the preceding paragraphs and others to be presented later. There remains the possibility that the attractant was precipitated with the soluble proteins or otherwise adsorbed with the insoluble proteins during the process of boiling the flesh; the residue, which may have contained the attractant, was not tested in the five experiments conducted with the boiled flesh.

Chemical tests were run on the clear centrifugate obtained after boiling of the extract. The Biuret test was positive, showing the presence of the amide link. The Xanthoproteic test was positive,

indicating the presence of the benzene ring. No positive test for protein was given on layering the solution over concentrated nitric acid. The lead test for sulphur was negative.

A series of experiments was conducted to compare the effects of precipitation by boiling and precipitation by salting out of the proteins on the attractiveness of the filtrate. The procedure and results are depicted in figure 8. Clear stock extract was boiled for 15 minutes and centrifuged; the centrifugate was divided into three equal parts, the first of which was tested (No. 85), the second of which was saturated with sodium chloride, centrifuged, and both centrifugate (Nos. 83, 86) and residue (No. 88) tested, and the third of which was boiled for an additional hour, centrifuged, and the centrifugate tested (No. 84). Strong responses were obtained with all tests except that with the residue (No. 88). The attractant was not removed with precipitation in either boiling or salting. Apparently fractionation was complete when both boiling and salting were used (compare Nos. 83 and 86 with No. 88).

The boiling and salting procedure was carried one step farther in two additional experiments. The centrifugate, after boiling and salting, was boiled to a residue. When re-dissolved in seawater, a positive response was obtained (Nos. 113, 121).

The possibility of precipitating or destroying the attractive substance by heat after it had been segregated in a relatively pure (protein-free) state by dialysis was next investigated. One liter of the dialyzate from a stock extract was boiled to 10 ml. and tested, producing a very strong response (No. 118). The residue from dialysis was boiled to a gummy residue, producing weaker but positive responses with both the 95-percent alcohol soluble portions and the alcohol insoluble portions (Nos. 114, 115, 116). In a second series, the dialyzate was boiled to dryness and a strong positive response was obtained with the portion of the residue which was soluble in absolute ethyl alcohol (No. 123). The solubility in absolute alcohol was confirmed in later experiments (Nos. 201, 281).

Thus the attractant is a substance comprised of a small molecule which is (at least, partly) soluble in absolute ethyl alcohol. This property rules out most of the known amino acids (except methionine and proline). However, that part of the attractant or attractants was insoluble in alcohol yet soluble in water is indicated by several experiments in which the alcohol-insoluble, water-soluble portion gave a positive response (Nos. 115, 116, 124, 183).

Because of the time required for dialysis and the incomplete separation that was achieved, attention was directed at

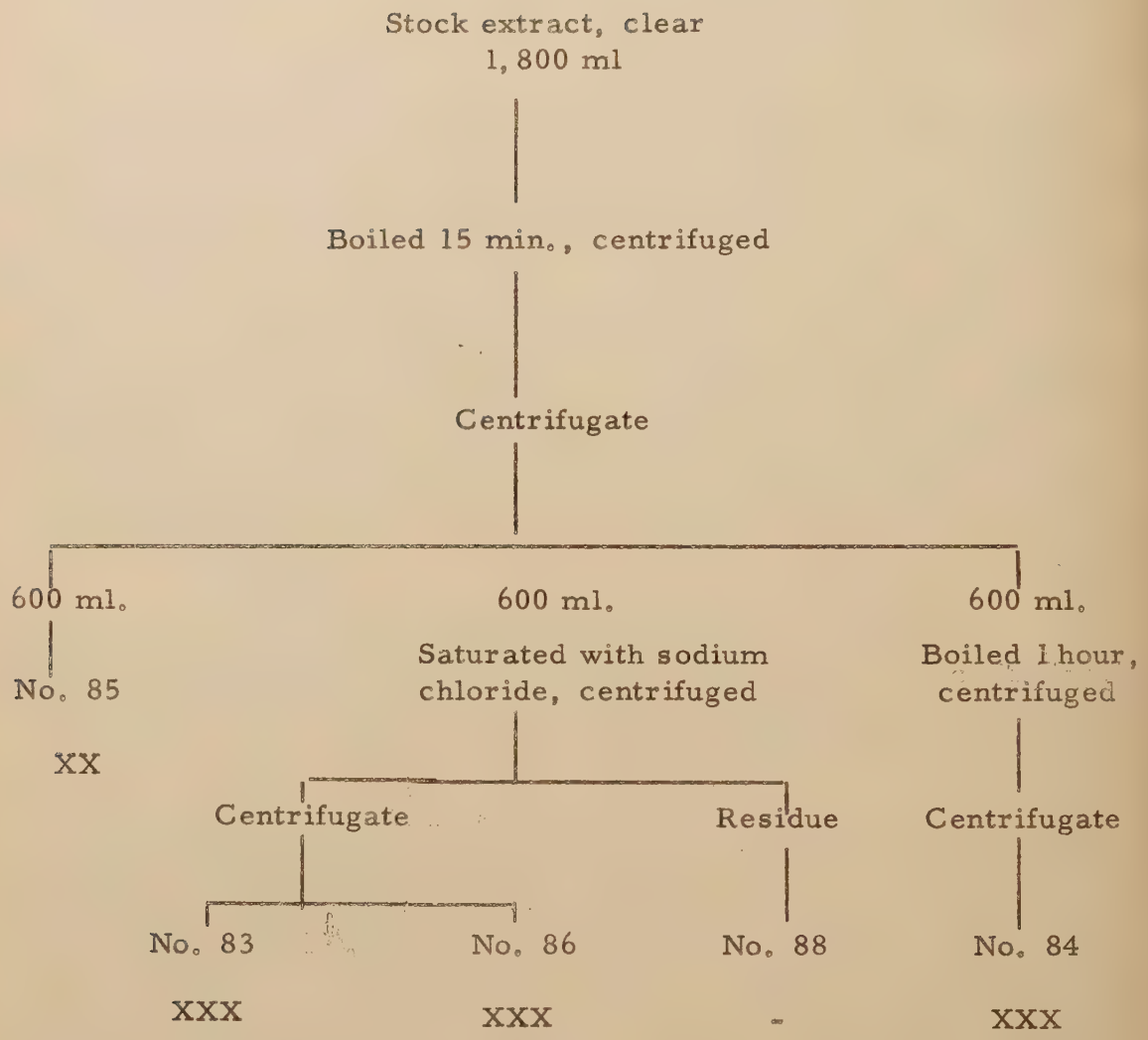

Figure 8.--Fractionation of stock extract of skipjack flesh: procedure and results in experiments Nos. 83 to 86, and 88.

the possibility of adsorption on various media. In one experiment, stock extract was concentrated by boiling, filtered, boiled with activated carbon, filtered, evaporated to a gummy residue, re-dissolved and tested, giving a positive response (No. 125). In another, the same procedure was followed except that after boiling with activated carbon the filtrate was treated with activated alumina, again with a positive response (No. 130). Similar results were obtained with anion (No. 133) and cation (No. 134) exchange resins. Apparently the attractant was not (completely) adsorbed on any of these media.

At this time (September 1952) the chemical work was undertaken at the University of Hawaii rather than the Hawaii Marine Laboratory; the tests, of course, were continued on the fish in Pond No. 5 at Coconut Island. To obviate the need for refrigeration and to facilitate condensation, extracts were prepared with 95-percent ethyl alcohol instead of water. The actual strength of the alcohol in the extract was less than 95-percent, depending on the quantity of water in the flesh and the relative quantities of flesh and alcohol which were used, but it was always strong enough to act as a preservative at room temperature. Numerous experiments showed that this alcohol extract promoted a strong positive response (Nos. 147, 163, 180, 235, etc.), whereas there was no response to alcohol alone (No. 19). However, complete extraction of the attractive substance with alcohol was difficult to attain. In two experiments, the flesh was treated with 95-percent alcohol for several hours and the alcohol, containing some of the attractant, was filtered off and used for further fractionation. The flesh was again treated with alcohol, and the alcohol filtered off and used. The flesh was then treated with water and the filtrate was tested. It still gave a strong response (Nos. 164 and 169) showing that the attractant had not been completely removed by the previous two alcohol extractions. To see if complete separation could be achieved with alcohol extraction, flesh was extracted twice with 95-percent alcohol as above. It was then further extracted with alcohol for 14 hours in the Soxhlet apparatus. The alcohol was then removed, and the flesh was extracted for an additional 12 hours with distilled water. The centrifuged water extract gave only a slight response (No. 17), indicating that almost complete extraction of the attractant had been achieved by the previous alcohol treatments.

Further attention was directed at fractionation of the alcohol extract by use of various adsorption media. To improve the technique, columns of the adsorbing media were prepared, through which the extract was allowed to filter slowly. Two portions were obtained, the filtrate or material which filtered through the column without being adsorbed, and the eluate or portion which was adsorbed

on the column and which was eluted or washed from it with various solutions such as water, weak acids, weak bases, alcohol, acetone, etc.

In a series of experiments with columns of activated alumina, zeolite, and activated carbon (Nos. 149 to 154) positive responses were obtained from both the filtrate and (water) eluate of the alcohol extract of skipjack flesh. However, the attractant appeared to be adsorbed most on activated alumina (No. 150) and least on activated carbon (No. 153). Adsorption on activated alumina was obtained in two additional experiments (Nos. 156 and 165), but complete separation of the attractant was not achieved (Nos. 155 and 162). Attempts at fractionation with alumina were abandoned in favor of anion and cation exchange columns.

Small white crystals which appeared in the (acetone) eluate from the activated carbon column, when dissolved in water, appeared to cause a positive response (No. 159). Further preparations gave no response (No. 167) and a doubtful response (No. 171). It was concluded that the positive responses were apparent rather than real and that the white crystals were not attractive. The attractive substance, for the most part, appeared in the filtrate from the carbon column. Thus either mixing or boiling activated carbon with the extract or passing the extract through a carbon column would remove certain inactive substances and constitute a stage of purification. This procedure was followed in some of the later preparations.

Another step in purification was the removal of fatty acids and related compounds which were soluble in petroleum ether or acetone. Van Weel (1952) found that the attractant was not soluble in petroleum ether. This finding was verified (Nos. 18, 142, 175, 177, etc.). It was also found that the attractant was not removed by extraction with acetone (No. 142).

Still another step in purification was the removal of inactive proteins by precipitation with tannic acid (No. 215), lead acetate (No. 197; Nos. 200 to 206; etc.), or barium acetate (Nos. 211, 212, 225) and the removal of purines and similar compounds as silver salts (Nos. 183, 184) or with phosphotungstic acid (No. 193, etc.).

Some of the above steps in purification either preceded or succeeded fractionation by adsorption on anion or cation exchange resins. Many different experiments, employing one to several successive stages of purification, were conducted. Two typical series only will be discussed to illustrate the procedure and results. Others may be followed from data given in the Appendix.

The first, a relatively simple series designed to determine whether the charcoal-purified, "fat-free" attractant was adsorbed on ion exchange resin columns, is illustrated in figure 9. An alcohol extract of skipjack flesh was passed through a column of activated charcoal; the filtrate was evaporated to dryness and extracted with petroleum ether and the residue was dissolved in alcohol and divided into two portions. One portion was passed through a Duolite C-3 cation exchange resin column and the filtrate collected and tested (No. 178); the column was then eluted with 5-percent sulphuric acid and the eluate was collected and tested (No. 181). The other portion was passed through a Duolite A-3 anion exchange resin column, and the filtrate was collected and tested (No. 179); the column was then eluted with 5-percent sodium hydroxide and the eluate was collected and tested (No. 182). In this particular series all tests were positive, but the eluate from the anion column (No. 182) appeared to give the strongest response.

The above results indicated that a further investigation of the adsorption on an anion column would be profitable, particularly to see (a) if complete adsorption of the attractant could be attained, (b) to see if the adsorbed material was completely removed by a water eluate, or if additional adsorbed material could be recovered with either a weak base or a weak acid and (c) to examine the solubility of the attractant in absolute alcohol. The series is illustrated in figure 10. A clear alcohol extract of tuna flesh was treated with lead acetate to remove proteins, filtered, and the filtrate was extracted with petroleum ether; it was then treated with hydrogen sulphide gas to precipitate the lead and excess gas was removed in vacuum. The filtrate was passed twice through a Duolite A-3 anion exchange resin column and the filtrate collected and tested (No. 200). The column was then eluted, first with water, next with a weak acid, and finally with a weak base. The water eluate was evaporated to dryness and dissolved in absolute alcohol (No. 201); the residue was dissolved in water (No. 202). The base eluate was similarly treated, giving an alcohol soluble portion (No. 204) and an alcohol-insoluble, water-soluble portion (No. 205). A positive response was obtained only with the alcohol soluble portion of the water eluate. In this series it appears that complete separation of the attractant was achieved by use of the anion exchange column and that the adsorbed attractant was completely removed by the water eluate.

In these and other experiments conducted during the autumn, it appeared that the attractant, purified to a varying extent, was not adsorbed on a cation exchange column, for positive responses were obtained with the filtrate (Nos. 142, 178, 216, 225) rather than the eluate. Only two tests were performed with the latter, however, one

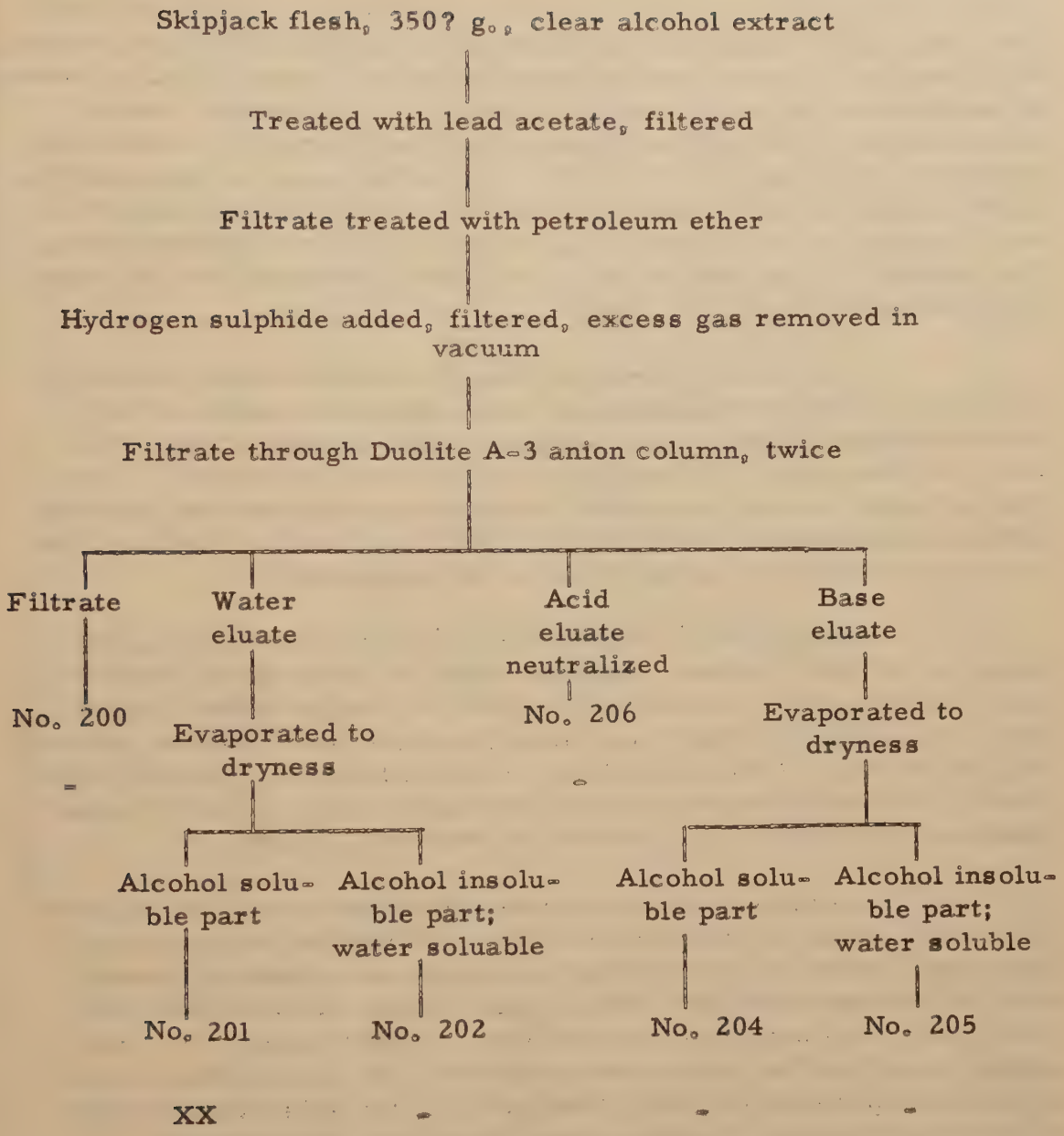

Figure 10.--Fractionation of an alcohol extract of skipjack flesh: procedure and results in experiments Nos. 200 to 202, and 204 to 206.

giving no response (No. 143) and the second giving a slight response (No. 181). More attention was directed to the anion exchange column, for it seemed to adsorb the attractant in several experiments as shown by moderate to strong (X and XX) positive responses with a water, dilute sodium hydroxide, or dilute ammonium hydroxide elutant (Nos. 182, 185, 193, 194, 201, 208, 213). Up to this stage of the study, the eluate failed to give a response in only two tests (No. 196 and 223) in which a response was expected on the basis of the preceding results. The filtrate, on the other hand, gave either a weak positive response or no response (Nos. 179, 200).

It was clear, however, that the attractant was held very "loosely" on the anion exchange column, appearing mostly in the first portion of the water or weak base eluate (compare Nos. 185, 186, 187; Nos. 208, 209, and 210; 213,214; 246, 247 and 248). The weak affinity (possibly not a true ion exchange) explains the failure of complete separation in some of the above experiments, and may have contributed to certain inconsistencies to be reported later.

Chemical tests were run on the attractant in its purest form yet attained, namely, that portion of the water eluate from the anion exchange column which was soluble in absolute ethyl alcohol (No. 201). Both the Biuret and Ninhydrin tests were positive, showing the presence of the amide link. The Xanthoproteic reaction was positive, showing the presence of the benzene ring. A test for phosphorus was positive, but a test for sulphur was negative.

In subsequent experiments which were run from the latter part of December on through the winter, the results became erratic. There was difficulty in obtaining meaningful and consistent results with the various chemicals used in purification, and also with the anion and cation exchange columns used in fractionation. For example, when barium acetate was substituted for lead acetate to precipitate the proteins and the filtrate was treated with sulphuric acid rather than hydrogen sulphide gas to precipitate the barium as a sulphate, no response was obtained (No. 211). Also there was no response for the solution that resulted when the protein precipitate of No. 211 was dissolved with nitric acid and the barium precipitated as a sulphate and filtered off (No. 212). The loss of activity, if real, may have been due to either destruction or CO precipitation of the attractant by the barium ion or by the sulphuric or nitric acid. That the barium ion was not responsible is shown by the series of experiments depicted in figure 11. An alcohol extract of skipjack flesh was acidified and treated with phosphotungstic acid to precipitate the purines. Barium acetate (in one experiment) and barium chloride (in another) was used to precipitate the phosphotungstic acid and the

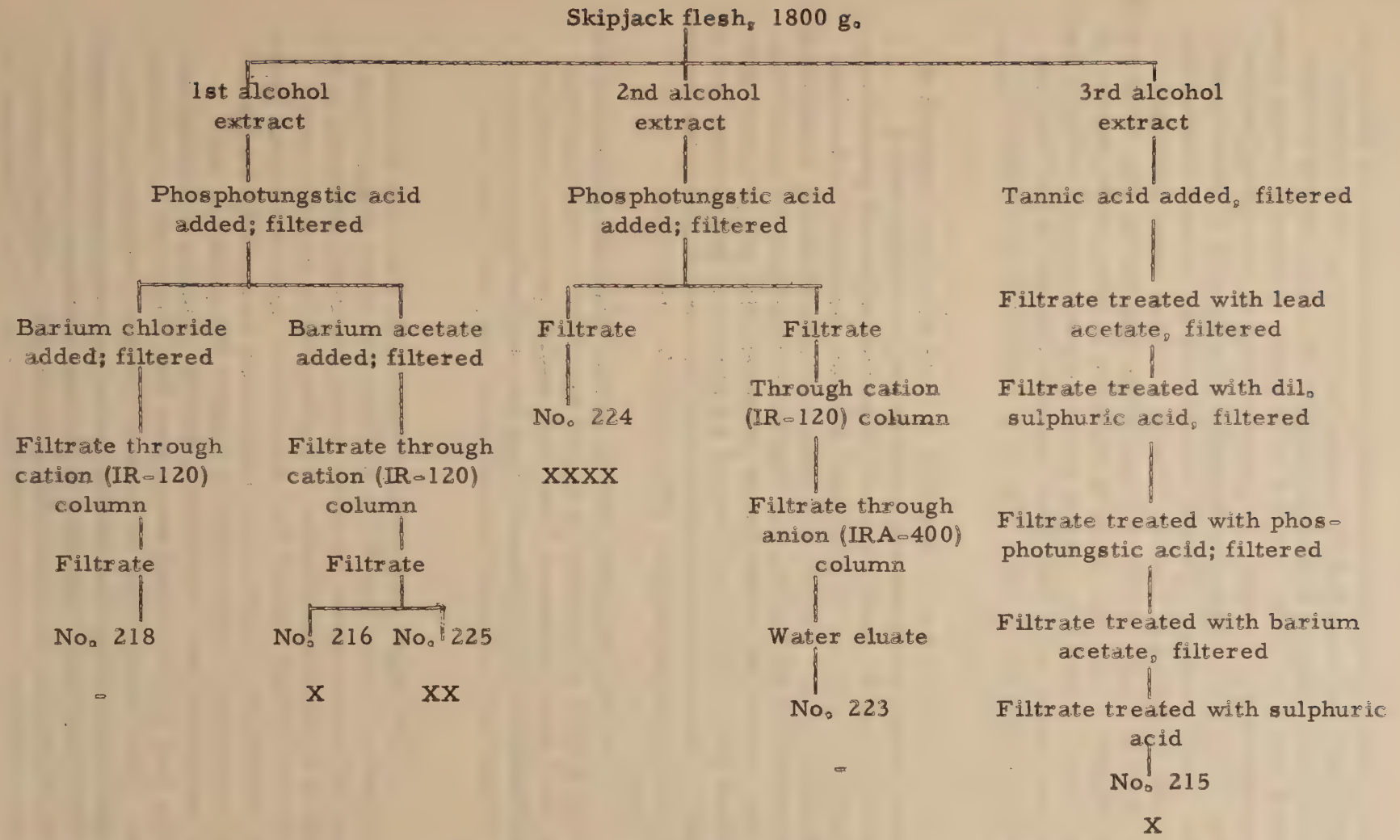

Figure 11.--Fractionation of alcohol extracts of skipjack flesh: procedure and results in experiments Nos. 215, 216, 218, and 223 to 225.

proteins. There was a good response when barium acetate was used, the barium ion was removed by passage of the material through a strong cation exchange column (Amberlite IR-120), and the filtrate was tested (No. 216, 225). On the other hand, strangely enough there was no response with exactly the same treatment, but using barium chloride (No. 218). When the material treated with phosphotungstic acid was passed through a strong cation exchange column (Amberlite IR-120), the filtrate was passed through a strong anion exchange column (Amberlite IRA-400), and the eluate was tested (No. 223), there was no response, although one was expected judging by the results of previous tests. However, a weak response was obtained with the final filtrate from a series of precipitations involving the use of both the barium ion and sulphuric acid (No. 215), following the method of Suzuki et al. (1909).

Inconsistent or negative results were also obtained in attempting to repeat the various purification and fractionation techniques discussed above on a self-digested extract of ground skipjack viscera, preserved with sulphur dioxide, supplied by Hawaiian Tuna Packers, Ltd. The extract itself promoted a strong response in some experiments (No. 219), but only weak responses in others (Nos. 229, 230). It could be cooked under pressure (No. 236) or extracted with alcohol (No. 235) without loss of its attractive properties, but it could not be carried successfully through the various precipitation nor ion adsorption processes (Nos. 232, 233, 234, 237, 238).

As skipjack flesh was no longer available, attention was directed at a study of extracts of bigeye tuna flesh. Simple alcohol extracts gave good responses (Nos. 239, 240). However, weak or negative responses were obtained when the purified materials were passed through ion exchange columns (Nos. 246, 247, 248, 256, 257, 265).

The negative results in these tests may have been due either to loss or destruction of the attractant at some stage of fractionation, or they may have been due to the moribund condition of the fish prior to a January mortality. To examine the former possibility a series of experiments with extracts of bigeye flesh was undertaken as illustrated in figure 12. The filtrate from alcohol extraction was treated with lead acetate to remove the proteins, and filtered; the filtrate was treated with sodium chloride to precipitate the lead as lead chloride, and was tested (No. 266) with an excellent response. The filtrate from the sodium chloride treatment, when boiled, gave only a slight response. Some loss may have been associated with boiling after treatment with lead, although a repeat of the procedure by heating on a water bath, rather than boiling, gave a very strong response in a later experiment (No. 273). When part of

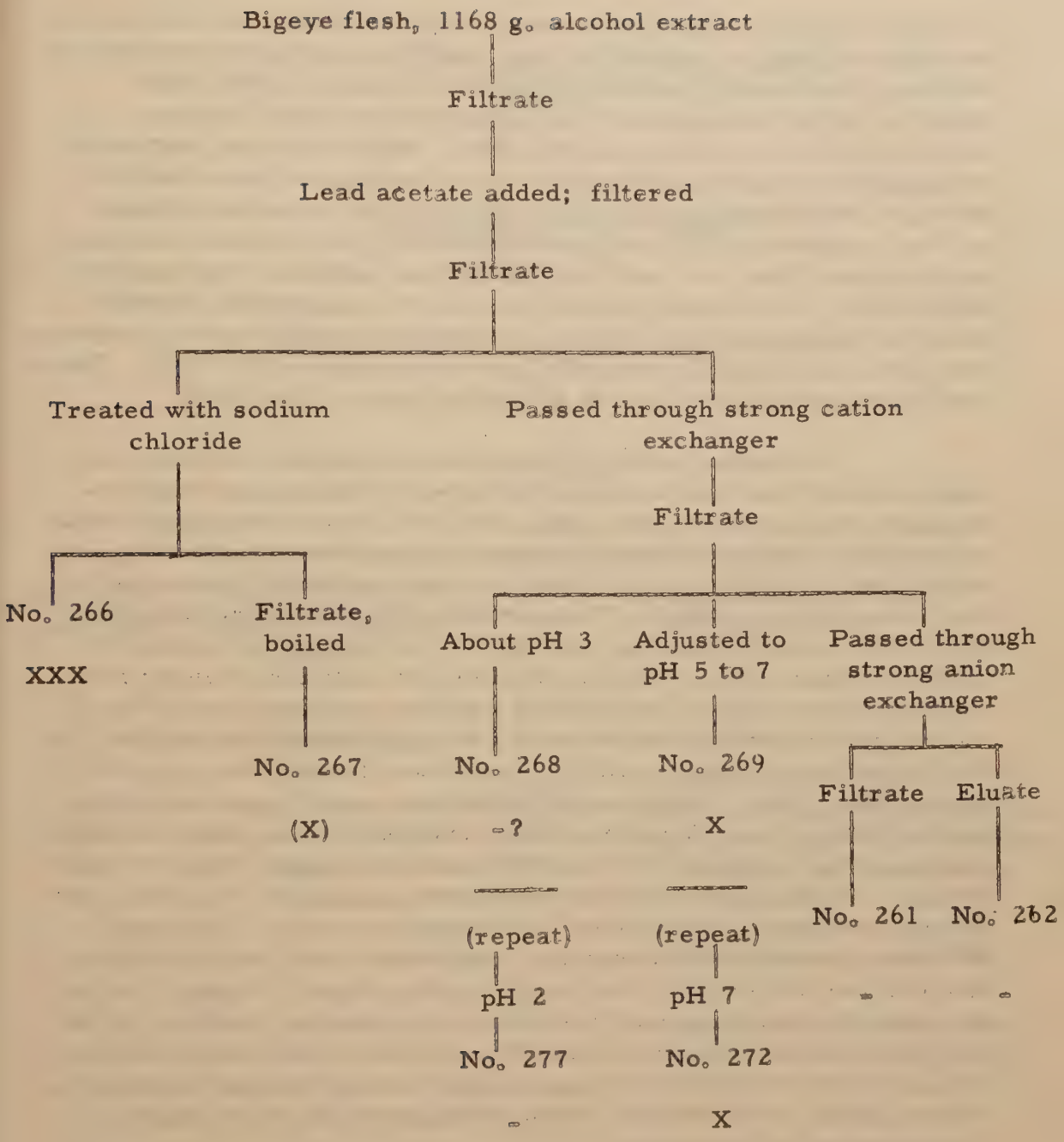

Figure 12.--Fractionation of an alcohol extract of bigeye flesh: procedure and results in experiments Nos. 261, 262, 266 to 269, 272, and 277.

the filtrate from the lead treatment was put through a strong cation exchange column to remove the lead, and the unadsorbed portion, or filtrate, was tested, there was no positive response (No. 268). When the pH of this material was adjusted from about 3 to near neutral, there was attraction (No. 269). When a further portion of the unadsorbed material from the cation exchange column was put through a strong anion exchange column and the adsorbed (eluate) and the unadsorbed (filtrate) portions tested, there was no response to either one (Nos. 261 and 262); the pH was unknown, but was probably basic. In a repeat experiment with the unadsorbed material from the cation exchange column, adjustment to pH 7 gave a response (No. 272), but adjustment to pH 2 gave no response (No. 277). There was the possibility that loss of attraction was related to pH.

In another series of experiments designed to check the stage at which loss occurred and the effect of strong and weak exchangers, bigeye flesh after extraction with alcohol was again treated with lead acetate, filtered, treated with sodium chloride (fig. 13), and divided into aliquots such that each test contained the treated extract from 400 g. of flesh. One portion gave an excellent response (No. 273) even after heating (see above). A second portion was passed through a weakly acidic (Duolite C-3) cation exchanger and the filtrate was tested, with a weak positive response (No. 278). A third portion was passed through a strongly acidic (Amberlite IR-120) cation exchanger and the filtrate was tested, with negative results (No. 274). Fourth and fifth portions were treated as above, but the filtrate from the strong cation exchanger was passed through a strongly basic (Amberlite IRA-400) anion exchanger (No. 275) and through a weakly basic (Duolite A-3) anion exchanger (No. 276), and the eluates tested, in each case with negative results. The only noticeable reaction with materials fractionated with ion exchangers was with the filtrate from the weakly acidic column. Again, the negative results may have been due to the unresponsive condition of the fish (although they reacted well in No. 273) or to the rather extreme changes in pH which occurred in passage through the ion exchangers --from about 7 to 3 with the cation exchangers and from about 3 to 12 with the anion exchangers.

Another series, designed to check the stage at which loss of the attractive substance occurred and the effect of pH, is depicted in figure 14. Yellowfin flesh was extracted with alcohol, the filtrate was acidified with hydrochloric acid to precipitate the lead as lead chloride (rather than as sodium chloride, as before), and filtered. One portion of the filtrate gave a good reaction when tested (No. 280). A second portion of the filtrate was evaporated to dryness over a water bath and dissolved in absolute ethyl alcohol,

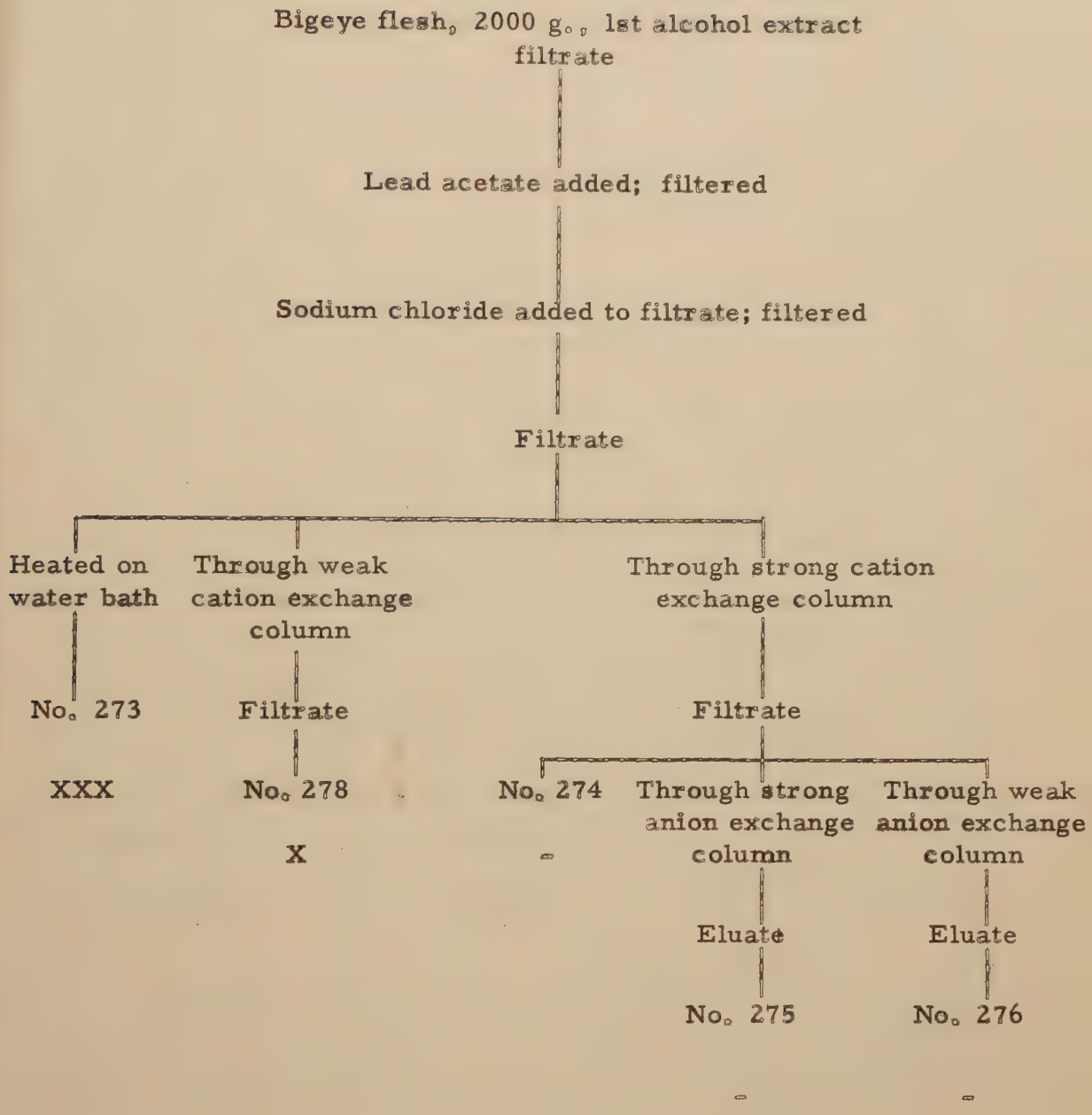

Figure 13.--Fractionation of a first alcohol extract of bigeye flesh: procedure and results in experiments Nos. 273 to 276, and 278.

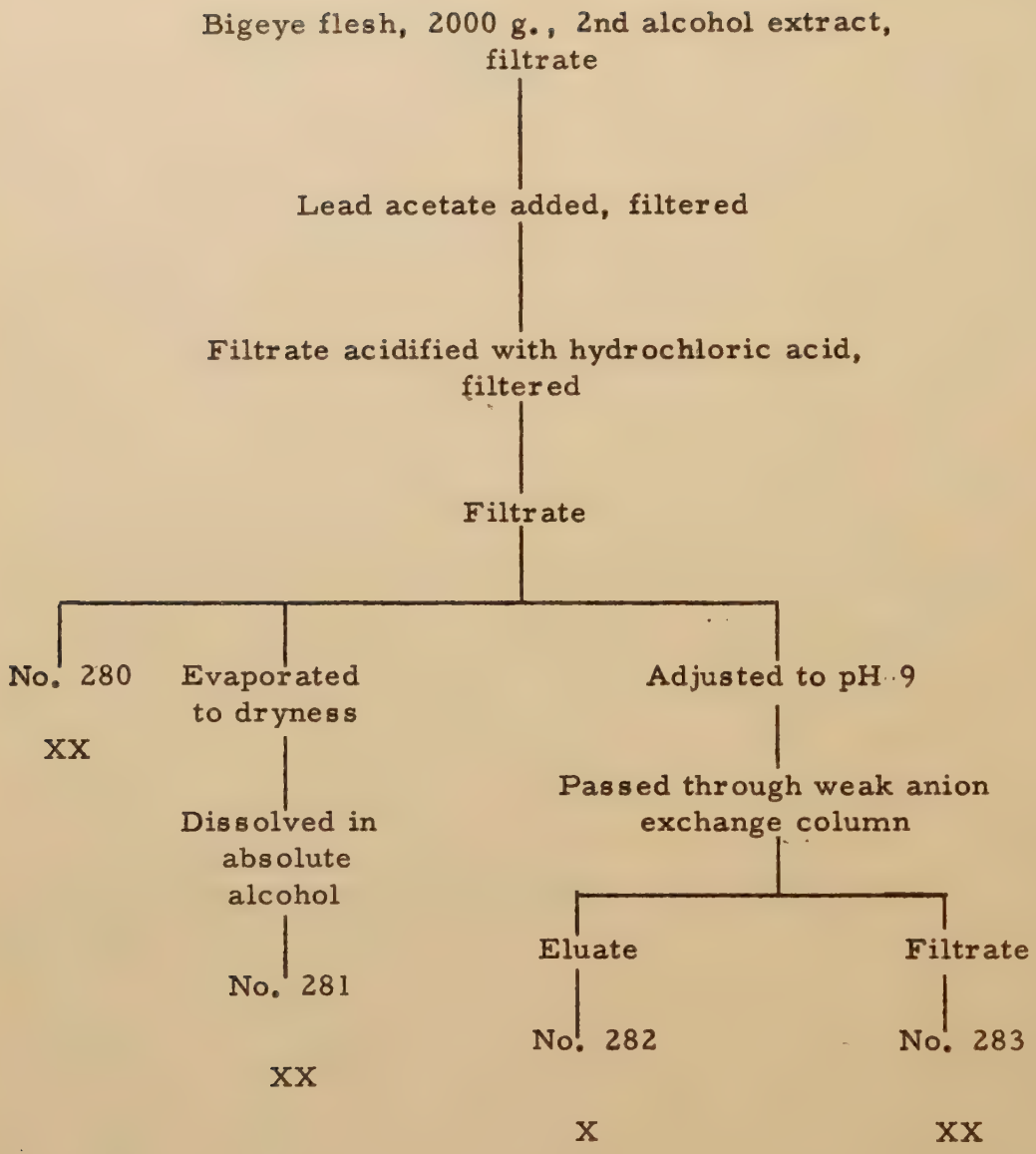

Figure 14.--Fractionation of a second alcohol extract of bigeye flesh: procedure and results in experiments Nos. 280 to 283.

again giving a good response when tested (No. 281). A third portion was adjusted to pH 9 with ammonium hydroxide, passed through a weakly basic (Duolite A-3) anion exchange column, and the adsorbed material was eluted with weak ammonium hydroxide and tested, giving a positive but weak response (No. 282). The unadsorbed filtrate, however, gave a stronger response (No. 283). Apparently there was only partial separation of the active substance on the anion exchanger. The fact that the results were generally positive, as compared with the negative results of the previous series, is surprising as they were based on a second and presumably weaker alcohol extraction of the same material as was used previously. The main differences were the precipitation of lead with hydrochloric acid rather than sodium chloride and the elimination of the cation exchanger, neither of which should have led to the differences. They may have been caused by either aberrant fish behavior or slight differences in technique.

In a third alcohol extraction of the same tuna flesh as used previously (fig. 15), the filtrate was treated with lead acetate, filtered, the filtrate was treated with hydrochloric acid, filtered, the filtrate was adjusted to pH 7, passed through a strong (Amberlite IR-120) cation exchanger, and the filtrate of pH 2 was tested with negative results (No. 285). When the filtrate from the cation exchanger was adjusted to pH 8 with ammonium hydroxide, there was a positive response (No. 286). When the material adsorbed on the cation exchanger was eluted with weak acetic acid and tested, it gave an even stronger response (No. 287). Again, the results are puzzling. On prior tests, the attractant had not been adsorbed (to any great extent, at least) on the cation exchanger. For the material that was not adsorbed, the attractive qualities seemed to be lost at a low pH.

At this time it was suspected that the variability and inconsistency of the results might have some relationship to the pH of the materials and the length of time they were subject to extremes of pH. In passing through cation and anion exchangers, and in other treatments which were used, pH's ranging from 2 to 12 were commonly induced for varying periods of time.

Several preliminary experiments with skipjack viscera preparations (Nos. 288, 289, 290; Nos. 295, 296, 297) and bigeye flesh preparations (Nos. 292, 293, 294) in which extracts exposed to pH's of 2, 7, and 10 were compared, gave inconsistent results but suggested that the response might be less at the two extremes; the mean (observational) scores for the three sets of experiments listed above were 1.0, 1.8, and 1.5 for pH's of 2, 7, and 10, respectively.

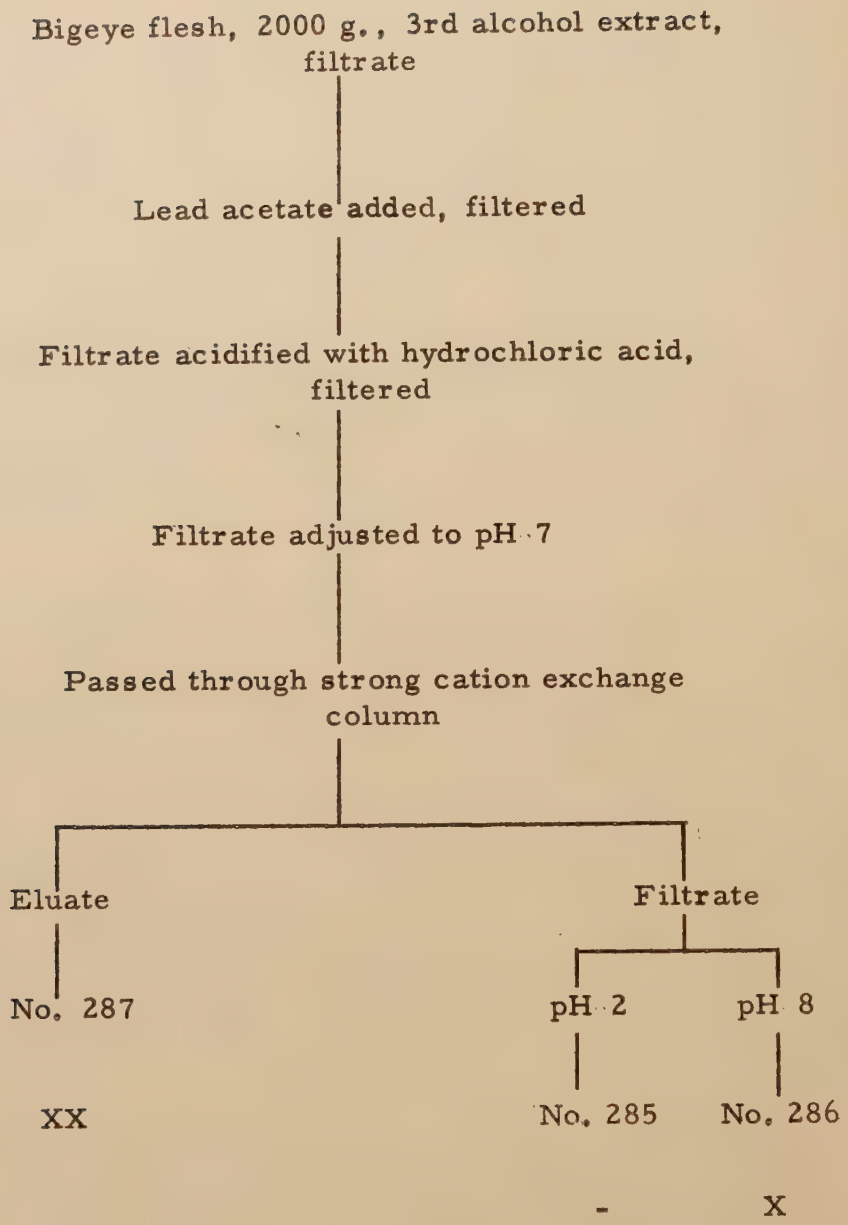

Figure 15.--Fractionation of a third alcohol extract of bigeye flesh: procedure and results in experiments Nos. 285 to 287.

A series of experiments was designed to test the hypothesis that the phosphate ion, assumed to be an integral part of the attractant, was made available at a high or low pH through hydrolysis, and that this was then precipitated (and lost) as magnesium ammonium phosphate by reaction with the seawater when the test substance was introduced. Bigeye flesh was extracted with alcohol and the filtrate was adjusted to pH 3 with hydrochloric acid to make the phosphate available for later removal. The filtrate was divided into six parts, each treated differently as shown in figure 16. Since there was a strong response to that part subjected to the most drastic method of removing the phosphate (No. 303), namely, adjusting to pH 1, boiling 15 minutes, adding 0.2 g. magnesium chloride, adjusting to pH 9, standing overnight, and then filtering and testing, the hypothesis that attraction is associated with labile or easily removed phosphate was discarded as untenable.

Finally, a series of experiments was designed to investigate the variability of the data (with only two tunny left in the pond), the effects of pH, and the effects of time lag between preparation of the material and testing. This series, conducted over a 3-week period in April 1952 (No. 313 et seq.), has already been discussed from the point of view of variability of the data. As may be calculated from table 3 (using eight complete replicates) the mean (observational) scores were 1.8, 2.1, and 1.3 at pH's of 2, 7, and 10, respectively. Although the results are suggestive of decreased response at the two extremes of pH, the differences when tested with either the observational or the quantitative data are not significant statistically. Moreover, the relative superiority of the acid and base are reversed as compared with the preliminary results given in a preceding series with skipjack viscera extract.

The preparations were made on a Saturday and were tested in two replicates on the following Tuesday or Thursday by one observer, and again in two more replicates on the following Saturday by a second observer. Thus the material tested by one observer was prepared for a shorter period of time than that tested by the second observer. The data, although incomplete for reasons discussed previously, yield 12 paired comparisons which may be segregated as follows according to time duration and pH:

	Shorter time (Observer 1)	Longer time (Observer 2)	Number of comparisons
pH 2	2.1	1.7	5
pH 7	1.4	2.1	4
pH 10	1.3	1.2	3

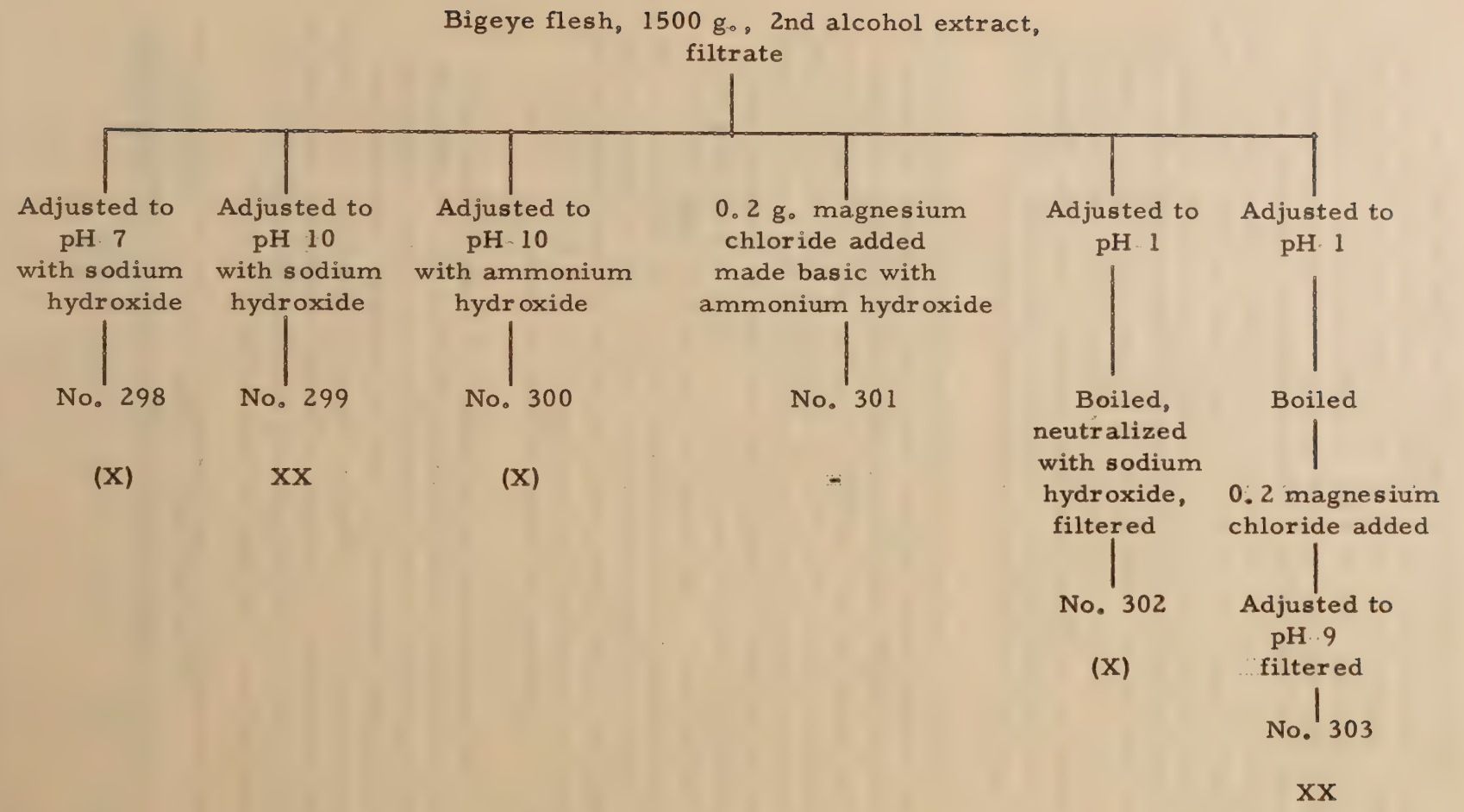

Figure 16.--Fractionation of a second alcohol extract of bigeye flesh: procedure and results in experiments Nos. 298 to 303.

The data suggest that at pH 6 the shorter the period between preparation and testing the greater the response. Again, however, the difference is not statistically significant. Moreover, an even greater difference in the opposite direction is present at the neutral pH 7. Also, of course, any differences due to time may be confounded with possible differences between observers.

The experiment provided no proof that differences in either pH or in time lag at various pH's caused differences in reponse. Rather, it emphasized the great variability of the response --a factor which doubtless contributed mostly to the erratic results encountered after the middle of December 1952. In view of this, further attempts at isolation and identification of the attractant were abandoned.

SUMMARY AND DISCUSSION

General

The present investigation, conducted from June 1, 1952 to May 31, 1953, is a study of the response of captive tunny to extracts of fish flesh, viscera, etc. and to certain chemicals in solution or suspension.

The tunas, caught by trolling, were transported to shore and established in a small concrete tank and a large pond at the Hawaii Marine Laboratory, Coconut Island, Oahu. For the most part, they were fed strips of tuna flesh 3 or 4 times a week and, on this diet, more than tripled their weight during the course of the year. The two tunny established in the tank during the summer of 1952 survived until the following summer. The population of 13 tunny, established in the pond, was decimated in two periods of mortality during the fall and winter; two fish survived to the following summer.

Test substances were introduced into the tank or pond through a continuous stream of water supplied by an electric pump. When and where possible, precautions were taken to avoid distraction of the fish by extraneous audio or visual stimuli.

When certain test substances such as clear aqueous or alcohol extracts of tuna flesh were introduced into the tank or pond, a response was obtained. This took the form of a feeding reaction and included one or all of the following components: speeding or acceleration of the swimming rate, a return to the area of distribution of the substance, surfacing, fanning-out and eventually a breakdown of school formation, circling, splashing, and biting at incidental objects on the surface of the water.

Although a positive response was obvious to the observer, it was extremely difficult to measure quantitatively because of its complexity and also at times because of erratic behaviour of the fish. Two quantitative measures were used, namely (1) the time out of 2- (tank) or 3- (pond) minute periods spent by the fish in an "attraction" area in which the test substance was dispersed, and (2) the number of "passes" (movements of each fish in one of two directions) in the attraction area. These measurements were usually made during five control periods (before introducing a substance) and during five test periods (after introducing a substance). A roughly quantitative (observational) measure of the strength of a response in one of five categories (- to XXXX) was also recorded for each experiment. With either measure, the response to the same test substance was extremely variable in both manifestation and strength, producing apparently inconsistent results in many of the replicated experiments.

It is postulated that in tuna flesh there is present a substance (or substances), herein called the attractant, which is perceived by the tunny through its sense of smell or taste and which promotes the urge to feed.

The attractant was present in the flesh, viscera, and blood of several species of tuna and also in the flesh and blood of certain white-fleshed fish. It was not present in beef blood. It was found in tuna cannery byproducts such as viscera preparations, stickwater, and fish meal.

Some 40 chemical compounds were tested as time permitted, including certain amino acids, vitamins, aromatics, proteins, etc. In some, notably certain amino acids, vitamins, and aromatics, there appeared to be a sensing of the dissolved or suspended compound but the results could not be duplicated. In no case did the response include all of the components of a typical reaction to a tuna flesh extract.

Nature of the Attractive Substance

Much of the work was devoted to attempts at purification, fractionation, and identification of the unknown attractant. Its properties are summarized in the paragraph which follows:

The attractive substance is soluble in water and alcohol but not in petroleum ether or acetone. It is not destroyed by cold or by heat (although it may be partly precipitated on boiling an extract which contains it). It is not precipitated by sodium chloride, tannic acid, lead acetate, phosphotungstic acid, or other substances which

remove proteins and purines. It will pass through a dialyzing membrane (in part, at least). It is not adsorbed (to any large extent) on activated carbon. It may be loosely adsorbed on columns of activated alumina or ion exchange resins. Of the latter, it appears to be held to a greater extent on an anion exchanger than on a cation exchanger, although the results are not consistent. It is affected slightly, if at all, by radical changes in hydrogen ion concentration. In its purest form yet attained, chemical tests showed the presence of phosphorus (but not sulphur), the amide link, and the benzene ring.

It is not yet possible to identify the attractive substance(s) from its chemical properties. It does not appear to be an amino acid, a fatty acid or lipoid, a purine, or a protein. In many of its properties it resembles Vitamin B_{12}, but this substance, while sensed by the fish, did not promote a typical positive response when tested.

Preservation of the Attractant

As sea testing of the extracts was contemplated, considerable interest centered on methods of preservation. Aqueous extracts of flesh and viscera could be kept for 2 or 3 weeks at temperatures at or just above the freezing point without excessive putrefaction and loss of activity. Aqueous extracts could be preserved indefinitely in a 2-percent solution of sulphur dioxide gas, sulphuric acid, phosphoric acid, or sodium bisulphite; apparently these chemical preservatives were not repulsive to the fish. Alcohol extracts could be kept indefinitely. Both water and alcohol extracts could be boiled to dryness, producing a dark brown, gummy residue which could be kept without deterioration for long periods of time, particularly if suspended on sodium chloride crystals; when the gummy substance was re-dissolved in water it was still attractive to the fish.

Possibility of Conditioning of the Fish

The question arises as to what extent the typical response to extracts of tuna flesh and viscera is promoted by a conditioning of the tunny to life in captivity and, particularly, to the type of food fed and the method of feeding.

The life of the tuna in the tank and pond differs greatly from that in the sea. The fishes' movements are limited by the walls and they fall into a pattern which is often precise and regular--much different from that of the open sea. Not only are their movements limited horizontally but they are also limited vertically by the shallowness of the water.

To survive in the pond or tank the tuna must become conditioned to feeding on inert, dead rather than motile, living food. After becoming conditioned to feeding on food such as strips of aku flesh, the fish appeared to have little interest in live food such as small baitfish (Stolephorus and Pranesus), which at times were present in the pond in fair abundance. On rare occasions they were observed to pursue the baitfish, which usually schooled near the seaward gates of the pond, but they would give up when the baitfish receded to a position close to the gates. They were not observed to actually capture any, and usually they ignored them. On the other hand, the tunas would almost invariably circle and snap at objects other than food which were thrown or fell accidently on the water surface (leaves, pieces of cellophane, etc.). This response was probably conditioned by the method of feeding. When a person appeared at the edge of the pond with a bucket of food, the fish would often see him and gather nearby, waiting for the food to be thrown to them. When it was thrown, they would follow its path and take it immediately it landed on the surface.

It is possible that they were conditioned to being fed at regular intervals of time (usually 4 p.m. every second day), although they would respond to the presence of both persons and food at any time except immediately after being fed.

As most of the extracts which were used were not visible to the fish, there is no doubt that the response was through the fish's sense of smell or taste rather than through its vision. However, there is the question as to whether the fish responded to skipjack flesh extracts because they were being fed pieces of skipjack, or closely-related tunas, as a regular diet. There is evidence that the response was not conditioned by the type of food which was fed.

Before and during the early experiments in the tank (to July 18, 1952) the one established tunny was fed a non-tuna diet (squid and baitfish), yet it still responded to extracts of skipjack flesh (Nos. 1, 8, 10) which it had not tasted while in captivity. Following April 25, 1953, the two tunny in the pond were fed exclusively on squid, yet almost 1 month later, May 19, 1953, they still responded to extracts prepared from skipjack viscera and yellowfin flesh (Nos. 350 to 356).

The fact that positive responses were obtained to extracts of fish other than tuna--aholehole (Nos. 49, 88, 105), jack (No. 96), and barracuda (No. 98)--while the tunny were still being fed skipjack is also evidence that the response was not conditioned by the species of fish which was being used as food. This, of course, is also

illustrated by responses to extracts of tunny and yellowfin while the fish were being fed on skipjack, and responses to extracts of skipjack while the fish were being fed yellowfin or bigeye tuna.

It may be concluded that the response of the tunny in captivity is not directly conditioned to the species of food which was fed. However, there still remains the possibility that the tunny formed a mental association between feeding and the smell or taste of the dead food, which was cut up or otherwise macerated and exuded juices of similar composition to the extracts. An association such as this would not necessarily be present in the case of wild fish feeding on whole living organisms at sea. This, or some other subtile type of conditioning to life in the pond, may have contributed to the response.

The part played by conditioning can be ascertained only by testing the extracts on schools of fish at sea. Certain materials for sea testing have already been prepared and pond-tested (Nos. 264, 279, 291, 304 to 312, 350 to 356). The results of sea tests of these and other preparations will be discussed in a later report. For the present it may be stated that the preliminary sea tests were largely negative.

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PART II

RESPONSE OF TUNA TO VISUAL AND VISUAL-CHEMICAL STIMULI

BY

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During September 1952 a few experiments were conducted on a population of 12 little tunny1/ (Euthynnus yaito) established in Pond No. 5 at Coconut Island, Oahu, to determine (1) whether visual lures would promote a tropistic response, (2) whether the response was heightened when combined with chemical stimuli, i. e., an extract of tuna flesh, and (3) whether the response varied with lures of different colors. It was hoped that the results would be of interest and value in devising lures which, either alone or in combination with extracts, would assist in attracting tuna to the stern of fishing vessels at sea.

METHODS

The lures consisted of 2-inch sections of 1/2-inch rubber tubing of different colors which were suspended from a cross bar attached to the tip of a 25-foot bamboo pole, pivoted near the point of balance (fig. 17). By means of a cord, a counterweight, and a system of pulleys, two lures, one suspended from each end of the cross bar, could be momentarily dipped into the water. When an experiment was in progress the lures were lowered about once every 2 seconds.

The lure array was fastened near the base of a 20-foot observation tower and could be manipulated from the platform on top. Observations of the fish were made when they entered the 39 x 75-foot attraction area (the same area that was used in chemical stimulation studies) marked off by two pieces of cord stretching across the pond.

Note: Contribution No. 48 of the Hawaii Marine Laboratory, University of Hawaii, Honolulu, T. H.

1/ The activity of one "sick" tunny was not recorded.

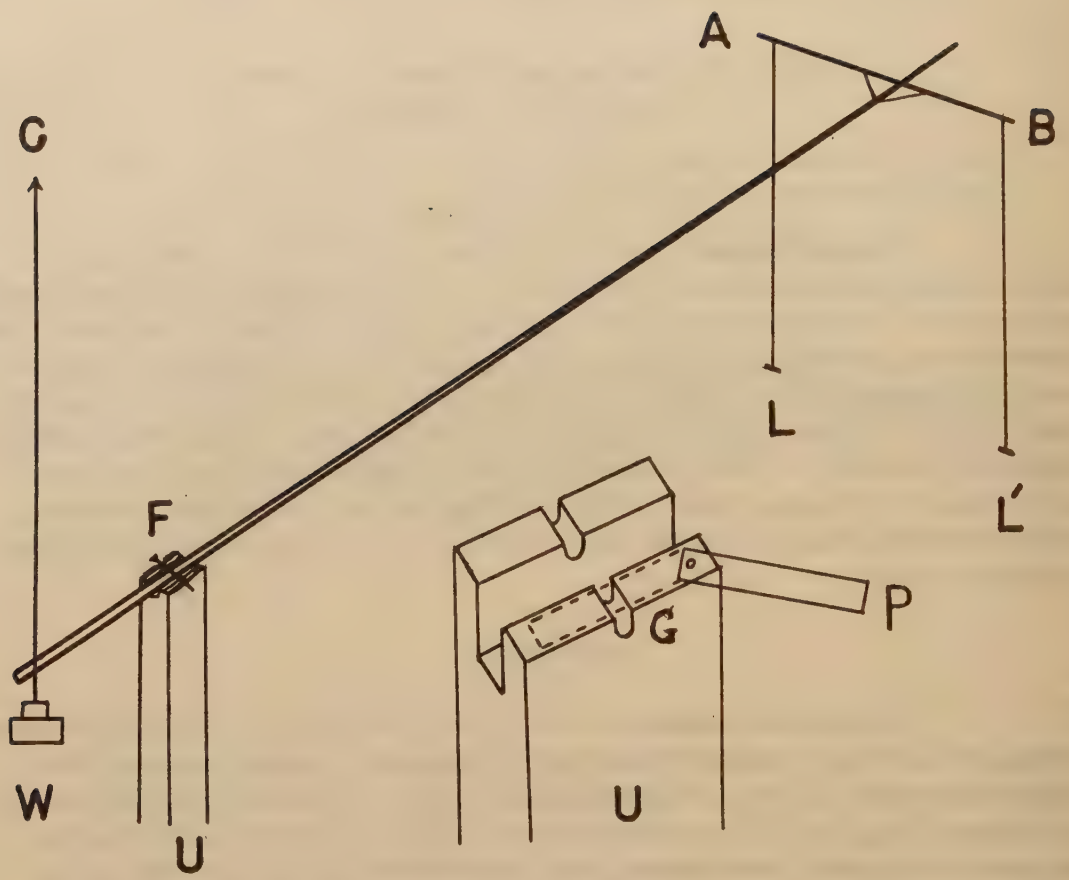

Fig. 17.--Diagram of mechanical device for lowering lures into water: AB - cross-piece; LL' - lures; U - supporting post; F - fulcrum; C - notch; P - plate to cover notch; W - weight; C - cord.

All experiments were conducted while the pump at the seaward or western end of the pond was operating. This projected a strong current of water into the first 1/10th of the pond and a weaker current into the second 1/10th, the attraction area. In some experiments, the lures only were used; in others, stock extracts of tuna flesh were introduced through the pump flow at the same time as the lures were presented. A detailed description of the pond, pump, stock extract, normal behavior of the fish, etc., is given in Part I of this report by Tester, van Weel, and Naughton, and the general arrangement for testing is shown in figure 4.

In a typical experiment the pump was switched on and the observers on top of the tower waited until the fish were behaving in a normal fashion, i. e., cruising slowly back and forth along the length of the pond in one or two schools. The activity of the fish was observed and recorded during a 15-minute control period (the data could be divided into 3-minute intervals). The lures were then dipped momentarily into the water once every 2 seconds and the activity of the fish was observed and recorded for a 15-minute experimental period. The colored lures were then reversed in position (switching left to right and right to left) and the observations were repeated. After two or more 15-minute experiments with lures, stock extract was added, the lures were dipped into the water, and observations of activity were made and recorded for another experimental period. The lures would then be switched, or changed, and the experiment repeated. In some of the early tests (9/3 and 9/5) the control and/or experimental periods were of shorter duration (9 or 12 minutes).

The behavior of the tunny, particularly during experimental conditions, was exceedingly complex. It was difficult to measure the activity with the usual devices--electrically controlled time clock, stop watch, and mechanical counter--and to record the data with pencil and paper, even when two observers were working together on top of the tower. A system of recording the behavior was worked out which consisted eventually of (1) the use of a tape recorder to give a running verbal description of the activity of the fish, and (2) the transcription of this information on the smoked paper of a kymograph drum by operating a series of levers to which styli were attached. The transcribing apparatus is illustrated in figure 18. It consists of a kymograph (F), a Franz kymograph timer (C) with two recording points, a lever (B) and stylus attached by a cord to the axle of a telephone dial (D) so that the length of the stroke on the drum is proportional to the number dialed, and a lever (A) and stylus attached by a rigid rod to a toggle key (E) which can be flipped up or down from a neutral position to make an up or down stroke on the smoked paper. The time is recorded by C, the number of fish in

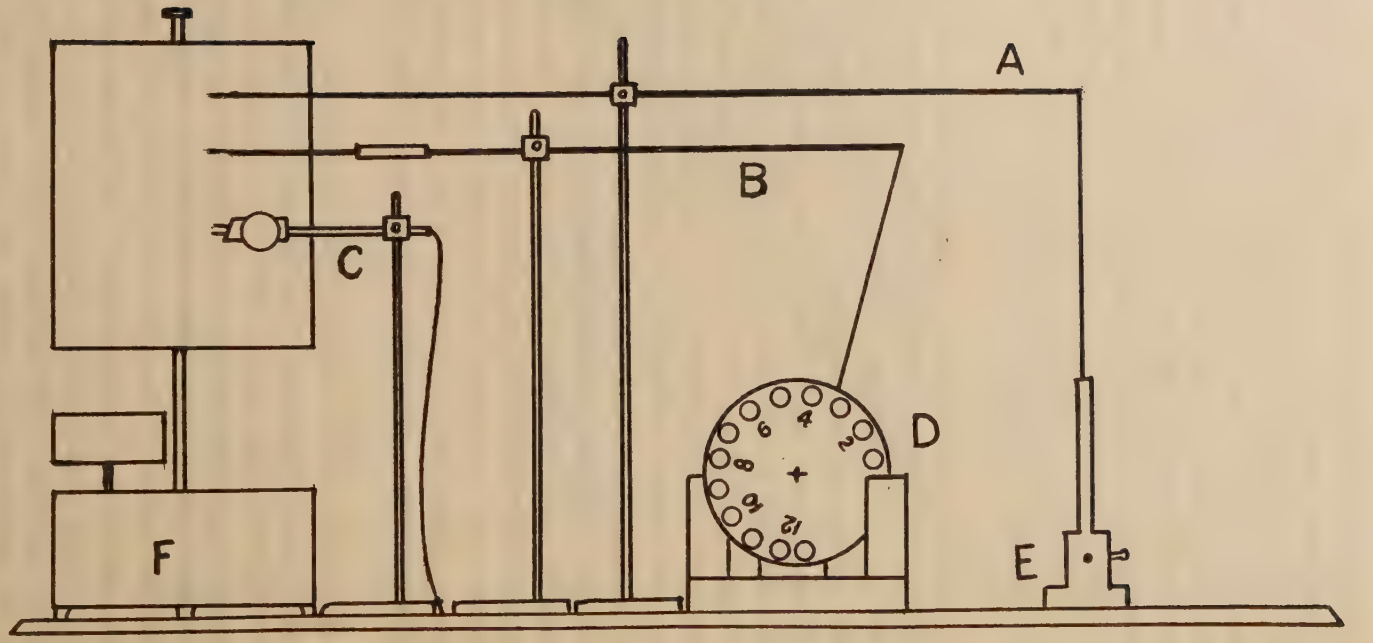

Fig. 18.--Diagram of transcribing-recording device: A - lever operated by toggle switch (E) for recording "passes"; B - lever operated by dial (D) for recording number of fish in area; C - timer; F - kymograph.

the area is recorded by B, and the number of passes at one (up) or the other (down) of the two lures is recorded by A. Typical recordings are shown in figure 19.

In addition to the above, the speed of the tunny was determined in several trials under control and experimental conditions by timing the leader of the school as it passed through the attraction area, using a stop watch.

RESPONSE UNDER CONTROL AND EXPERIMENTAL CONDITIONS

The pattern of activity of the fish was observed under control and experimental conditions and is discussed below. The activity was measured quantitatively in several different ways, each of which will be presented and discussed in the sections to follow.

Pattern of Response

During control periods the tunny, usually in one school or in two schools of unequal size, swam slowly back and forth along most of the length of the pond, looping in deeper water near the ends, or often pausing to "play" in shallower water at the ends before looping.

A kymograph record of observations during a 15-minute control period in one experiment is shown in figure 19A. It is discussed in detail to illustrate the interpretation of the kymogram. The first histogram shows that 22 seconds after the start, a school of 12 tunny entered the field from the east. After spending 24 seconds in the field, they left by the same side as they came in, and swam to the eastern end of the pond. After 165 seconds the school returned and swam through the field in 10 seconds, as shown by the second histogram. The school looped in the western 1/10th of the pond during a 9-second interval and re-entered the area from the western side. As shown by the third histogram, they sped through the field in 8 seconds. After 147 seconds the schools re-entered the area from the east, stretched out in linear formation, with the leader entering the field about 6 seconds ahead of the 12th tunny (fourth histogram). After leaving the field, the school spent 84 seconds in the western 1/10th of the pond, during which time they circled in the shallow southwestern corner near the pump. After passing through the field for a fifth time, the tunny stayed in the eastern part of the pond for a long period--about 4 minutes--before returning to pass through the area (sixth histogram). When they entered the area, 2 turned back, but 10 passed through to spend 60 seconds in the

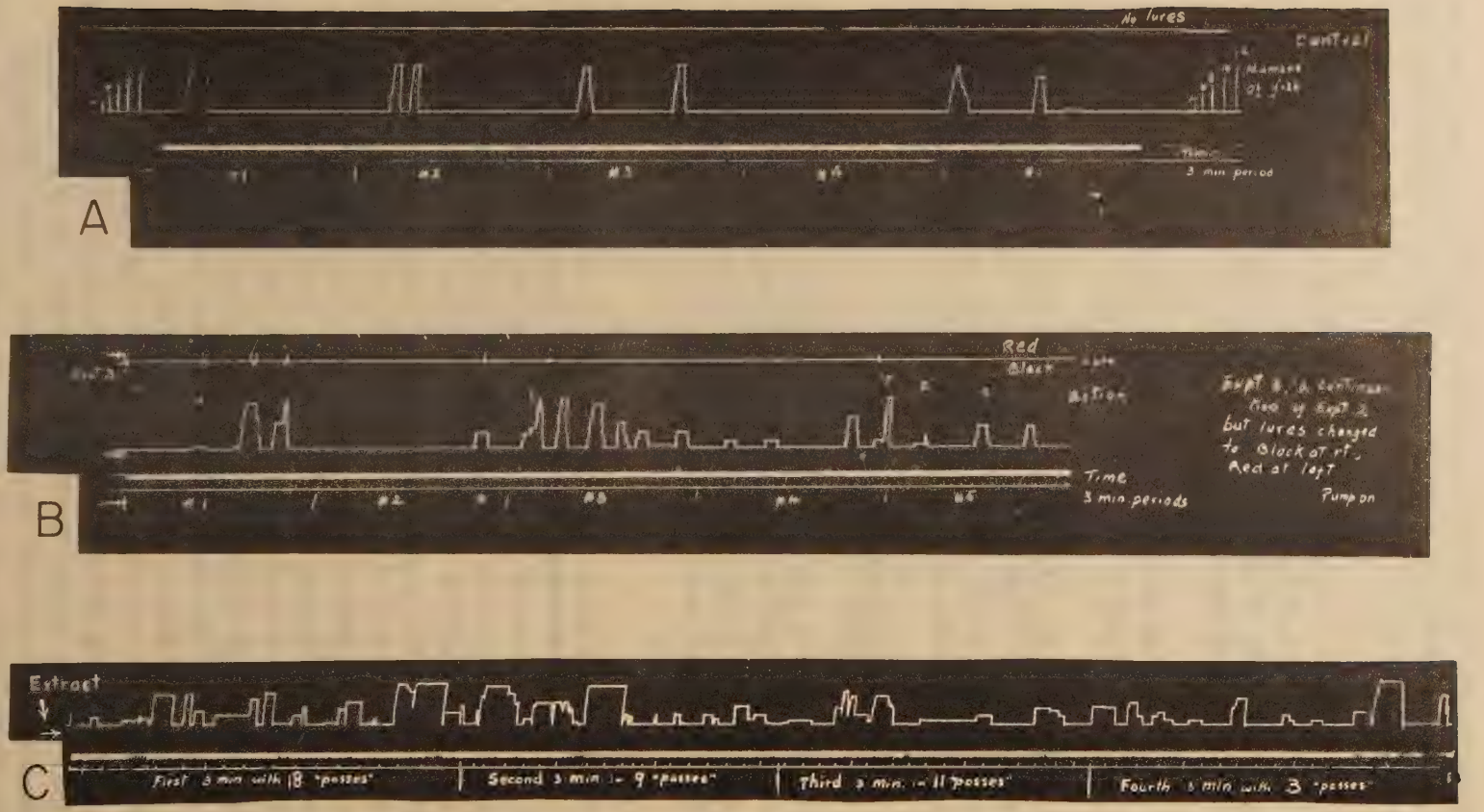

Fig. 19.--Typical kymograms: A - under control conditions; B - when stimulated by lures; C - when stimulated by lures plus extract.

western 1/10th of the pond. On turning back they sped eastward through the field in 12 seconds (seventh histogram). The two tunny which separated from the school earlier circled slowly outside the eastern border of the field, and 15 seconds after the major school left these two fish re-entered the area and swam inside for 18 seconds (eighth histogram).

When a pair of colored lures was lowered repeatedly into the water inside the attraction area, one or more tunny might be moving westerly towards the area and near enough to see the moving objects. In this case they would usually swim toward the lures and try to take them. It often happened that when one or two tunny started to bite, the others near them would become active and circle back to the lures. On the other had, if the tunny were at the far end of the pond, the lures might be lowered repeatedly for a long time without any response from the fish until they approached the attraction area. When taking after the lures, the speed of movement was not noticeably increased compared with that during the control period.

Figure 19B shows the reaction of the tunny in an experiment in which two lures, one red and the other black, were presented. They entered the field 17 times in groups of different sizes. In the third 3-minute interval, attraction and excitement is indicated by the close spacing of the histograms. The symbols "C" and "O" in the figure indicate looping and circling, respectively, inside the area. From the strokes indicating the response to the lures (upper line), it will be seen that they attempted to "take" the red lure 8 times and the black lure 6 times.

When a stock extract of tuna flesh was introduced through the stream of water at the western end of the pond the tunny would become greatly excited as soon as they sensed it. Usually the extract was propelled into the attraction area about 1 minute after its introduction. The fish would dash about with increased speed, biting at floating objects such as leaves and sticks, as well as running for the lures and fighting among themselves. There was a clearly visible feeding reaction. But after 10 to 15 minutes the response would gradually disappear and they would assume a pattern similar to that seen when lures alone were used.

In figure 19C a kymograph record of the response to lures and extract is seen. The number of passes at the lures is indicated by numbers rather than by strokes. The great excitement when extract was added is evident from the increased frequency of the histograms, together with their varied shape. The fish took the

lures 18 times in the first 3-minute interval, 9 times in the second, 11 times in the third, and 3 times in the fourth.

These and other kymograph records are analyzed more extensively in the sections which follow.

School Entrances

The activity under various conditions of stimulation may be measured by the number of schools (of varying size) entering the attraction area during a 15-minute period. The results of the experiments are summarized in table 4. In this, and other tables to follow, the data for September 5 and 9 have been adjusted to a 15-minute period. The results for similar experiments conducted on the same day have been averaged.

It will be seen that on each day schools entered the attraction area more frequently (as compared with control conditions) when a pair of colored lures was dipped into the water, and still more frequently when lures were used together with extract. The grand mean number of entrances was 6.7 for controls, 14.6 for lures, and 21.6 for lures plus extract. Obviously the differences between the means are statistically significant.

Table 4.--Summary of data on the number of schools entering the attraction area under various conditions of stimulation

Condition	Date						
	9/3	9/5	9/8	9/10	9/12	9/17	Mean
Control	10	5	9	3	7	6	6.7
Lures	19.25	13	-	12.5	16	12	14.6
Lures plus extract	38.25	21.25	22.33	14.00	16.75	17	21.6

Percentage of Time in Area

The percentage or relative time spent by the fish in the attraction area is summarized in table 5 for the various conditions of stimulation. On the average the time spent in the area was 12.0

percent during control conditions, 24.5 percent when two lures were used, and 29.5 percent when the lures plus extract were used. A rough test (using "t") of significance of the difference of the paired observations (neglecting the varying intrinsic accuracy of the mean determinations for each day's experiments) indicates a significant difference between control and lures (mean difference, 13.8 percent; $P < 0.01$), but not between lures and lures plus extract (mean difference, 4.0; $P = 0.2$).

Table 5.--Summary of data on percentage time spent in the attraction area under various conditions of stimulation

Condition	Date							
	9/3	9/5	9/8	9/10	9/12	9/15	9/17	Mean
Control	9.6	6.9	20.0	4.0	14.0	15.6	14.2	12.0
Lures	27.0	17.0	-	23.5	32.7	23.8	23.1	24.5
Lures plus extract	35.0	27.8	33.7	21.3	32.7	-	26.4	29.5

Fish-seconds in Area

The summation of the product of the number of fish and time spent in the area is probably a better measure of activity than the two measures discussed above. This is equivalent to summing the areas under the histograms in the kymograph records, and may be expressed in fish-seconds per 15-minute period. The results are given for individual experiments in table 6.

In comparison with the controls, it will be observed that the number of fish-seconds is generally greater when the lures are used, and slightly greater still when the lures are combined with extract. The grand means for control, lures, and lures plus extract are respectively 114.3, 352.8, and 364.8 fish-seconds. In experiments with lures (alone) which were repeated in succession on the same day, the measure tends to fluctuate rather widely, showing neither a consistent increase nor decrease in response. In experiments with lures plus extract, the measure tends to decrease with repeated stimulation, indicating a dulling of the response. There are five comparisons of control, lures, and lures plus extract involving

Table 6.--Number of fish-seconds spent in the attraction area under various conditions of stimulation

Date	Condition		
	Control	Lures	Lures plus extract
9/3	47	(1) 253 (2) 640 (3) 101	(1) 522 (2) 107
9/5	100	(1) 683	(1) 371
9/8	120	-	(1) 657 (2) 310 (3) 345
9/10	34	(1) 646 (2) 165	(1) 380 (2) 167
9/12	135	(1) 453	(1) 504 (2) 319 (3) 292 (4) 289
9/15	124	(1) 207 (2) 168 (3) 115	-
9/17	240	(1) 80 (2) 370	(1) 635 (2) 209

initial experiments, indicated as "(1)" in table 6. These yield the following comparable means: 111.2, 423.0, and 482.4 fish-seconds, respectively. Obviously, the means for both lures alone and for lures plus extract are both significantly greater than that for controls. Although the mean for lures plus extract is greater than that for lures, the statistical significance of the difference cannot be established with the present data.

Speed of Swimming

Another measure of activity is speed of swimming. This was determined by timing the leader of the school as it passed between the two lines marking the boundary of the attraction area.

Sources of error include the effect of parallax in determining when the fish is exactly below the lines, deviation from a path exactly perpendicular to the lines, and deviation from a horizontal plane. However, variation induced by these sources of error is small compared with the variability from trial to trial. The results of observations under control and experimental conditions are summarized in table 7.

Table 7.--Summary of data on speed of swimming under various experimental conditions

Condition	Number of observations	Mean time and standard error	Mean speed (feet/second)
Control	12	18.42 ± 1.60	2.12
Lures	12	15.08 ± 0.90	2.59
Lures plus extract	20	10.15 ± 0.63	3.84

The mean speed of swimming increased beyond that of the controls when the tunny were stimulated by lures, and it increased still more when they were under the combined stimulus of lures and extract. The mean difference between control and lures is not significant statistically ($P \cong 0.08$). However, that between lures and lures plus extract, and also that between control and lures plus extract are both highly significant ($P < 0.01$ in each case). The increased rate of swimming of the tunny when stimulated by the extract was obvious to the observer. The actual mean swimming rate under these conditions (3.84 feet per second) is equivalent to 2.6 miles per hour. Of course, bursts of speed several times this magnitude were frequently observed.

Feeding Activity

Feeding activity may be measured by the number of passes (bitings or attempted bitings) at the lures both when used alone and when used in conjunction with extract.

Table 8 shows the mean number of passes at the lures per 15-minute period on 5 successive days. The grand means for lures and for lures plus extract are respectively 14 and 40 passes

per 15-minute period. The increased feeding response under the additional stimulation of extract is apparent without further statistical analysis. The data are not suitable for isolating and testing the component of variance associated with daily variation in response.

Table 8.--Mean number of passes at lures under two experimental conditions

Date	Condition	
	Lures	Lures plus extract
9/3	26.7	51
9/5	13	20
9/10	10.5	40
9/12	6	29
9/17	14	20

RESPONSE TO LURES OF DIFFERENT COLORS

Each lure of a pair differed from its mate in color. The following combinations were tried: white-red; white-black; white-silver; red-black; and silver-black. As already explained, the positions of the lures were interchanged between experiments. The number of passes at each lure per 15-minute period was determined when lures were used alone and when they were used in combination with extract. The results are summarized in table 9.

From the table it will be observed that the white lures received either the same or, more usually, a greater number of passes than the colored lures (either tested alone or with extract) when paired with red, black, or silver lures. Similarly, the red lure seemed superior to the black in number of passes. However, none of the ratios, either individually or grouped according to similar experiments, differ significantly from a 1:1 ratio when tested with Chi-square. From the pooled data for white versus all other colored lures with which it was paired there is evidence of the superiority of white. The ratio of pooled values for white vs. color is 155:122 which, when compared with the hypothetical 138.5:138.5,

yields an adjusted Chi-square of 3.7 with one degree of freedom ($P = 0.06$), which could be regarded as evidence for rejecting the hypothetical equality ratio. Although there is this evidence of a significantly greater number of passes at the white as compared with the colored lures, the superiority of the white lure is slight. Knowing that the tunny will make a pass at any inanimate object which appears on the surface, including not only lures but also leaves, sticks, pieces of paper, etc., the slight superiority of the white lure may perhaps be attributed to its greater visibility. There is no assurance that this superiority would be manifested in the sea, where conditions of sea water transparency and background color would be much different from those in the pond.

Table 9.--Number of passes at paired lures of different colors under two experimental conditions

Colors of paired lures	Conditions	
	Lures	Lures plus extract
White-red	(1) 5-5 (2) 10-8	(1) 31-27 (2) 7-4
White-black	(1) 8-5 (2) 4-4	(1) 10-9 (2) 12-7 (3) 7-2 (4) 21-19 (5) 6-5 (6) 15-10
White-silver	(1) 8-8	(1) 11-9
Red-black	(1) 3-3 (2) 9-9	(1) 23-20 (2) 16-13 (3) 9-6
Silver-black	(1) 11-8	(1) 12-12

SUMMARY

The activity of 12 little tunny in a large pond was observed during September 1952 under control conditions (no stimulation), when a pair of lures was dipped into the water once every 2 seconds, and when the lures were used together with stock extract of tuna flesh.

Observations were made in an "attraction area" which could be viewed from the top of a 20-foot tower. Activity was recorded verbally on a tape recorder, and later transcribed to a kymograph drum. The kymograms furnished quantitative data on activity.

As compared with control conditions, schools entered the area more frequently when stimulated with the lures, and still more frequently when stimulated with lures plus extract.

As compared with control conditions, the fish spent more time in the area when stimulated with lures, and still more time when stimulated with lures plus extract. However, the difference in relative time between the two experimental conditions was not statistically significant.

When activity was expressed as number of fish-seconds per unit time in the area, the results were similar to the foregoing. When lures and extract were used together, there was a dulling of the response with repeated testing.

The use of both lures and extract increased the rate of swimming from an average of 2.12 feet per second for controls to an average of 3.84 feet per second.

The fish made many more passes at the lures when stimulated with extract, showing a heightened feeding response.

Although, in general, the fish made more passes at white as compared with colored lures, the superiority of the white lures was slight. It may have been associated with greater visibility rather than color preference. There is no assurance that white lures would be superior to colored lures in the open sea.

APPENDIX

A summary of experiments on chemical stimulation conducted in tank (T) and pond (P) by van Weel (vW), Tester (T), or Naughton (N), over the period July 1, 1952 to May 19, 1953, with reaction classified in categories ranging from "-" to "XXXX".

Expt. No.	Date 1952	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
1	7/1	Skipjack flesh, 150 g. extracted with 300 ml. water: centrifugate.	T	vW	XXXX	Tunny had not previously been fed skipjack flesh.
2	7/1	Same as No. 1: murky residue.	T	vW	-	Visual attraction only.
3	7/8	Ovaries, skipjack, 250 g. extracted with 500 ml. water, not centrifuged: whole extract.	T	vW	-	Cloudy material apparently repellent.
4	7/8	Testes, yellowfin, 400 g. extracted with 800 ml. water, not centrifuged: whole extract.	T	vW	-	Erratic behavior.
5	7/11	Skipjack flesh, 220 g. boiled 10' in 500 ml. water, filtrate.	T	vW	-	Erratic behavior.
6	7/11	Wahoo flesh, 170 g. extracted in 440 ml. water: centrifugate.	T	vW	-	No indication of attraction.
7	7/11	Same as No. 6: murky residue.	T	vW	-	"
8	7/14	Skipjack flesh, 225 g. extracted with 750 ml. water, not centrifuged: whole extract.	T	vW	X	Erratic behavior, but definite attraction.
9	7/14	Skipjack flesh, 282 g. boiled 10' with 600 ml. water: filtrate.	T	vW	-	

Expt. No.	Date 1952	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
10	7/18	Skipjack flesh, 225 g. extracted with 500 ml. water: centrifugate.	T	vW	XX	Definite reaction.
11	7/18	Skipjack flesh, 282 g. boiled 10' with 600 ml. water: filtrate.	T	vW	-	
12	7/22	Skipjack flesh, 350 g. boiled 10' with 500 ml. water: filtrate	T	vW	-	Visual attraction to investigator at start.
13	7/22	Skipjack flesh, 240 g. extracted with 400 ml. water: centrifugate.	T	vW	X	Very slight attraction.
14	7/24	Yellowfin flesh, 50 g. extracted with 150 ml. water: centrifugate.	T	T	XX	Definite attraction.
15	7/24	Same as No. 14, murky residue.	T	T	XX	Definite attraction.
16	7/25	Skipjack flesh, 227 g. extracted with 500 ml. water: centrifugate.	T	vW	-	Fish had been fed 2 hours previously, slight attraction at beginning only.
17	7/28	Testes, yellowfin, 230 g. extracted with 500 ml. water, not centrifuged: whole extract.	T	vW	-	
18	7/28	Yellowfin flesh, 100 g. extracted with 200 ml. water: centrifugate treated with 3 x 50 ml. petrol ether.	T	vW	XX	

Expt. No.	Date 1952	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
19	7/28	Ethyl alcohol, 60 ml.	T	T	-	Records lost.
20	7/28	Skipjack flesh, 203 g. extracted with 600 ml. water: centrifugate.	T	vW	XX	New fish present were distracting.
21	7/28	Skipjack flesh, 172 g. boiled 10' with 500 ml. water: filtrate.	T	vW	-	
22	7/28	Anethol, 6 ml.	T	T	(X)	Apparent attraction ?
23	7/29	Yellowfin blood, 100 ml. extracted with 500 ml. seawater, filtered through cheesecloth: filtrate.	T	T	XXX	
24	7/29	Yellowfin skin, 44 g. extracted with 300 ml. seawater: whole extract.	T	T	-	Possible visual repulsion.
25	7/29	Yellowfin liver, 82 g. extracted with 300 ml. seawater, filtered through cheesecloth: filtrate.	T	T	XX	
26	7/29	Yellowfin flesh, 100 g. extracted with 1000 ml. seawater, filtered through cheesecloth: filtrate.	T	T	X	
27	7/31	Tunny flesh, 100 g. extracted with 200 ml. dist. water, filtered through cheesecloth: filtrate.	T	T	XX	Attraction evident.

Expt. No.	Date 1952	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
28	7/31	Tunny liver, 95 g. extracted with 200 ml. dist. water, filtered through cheesecloth: filtrate.	T	T	XXX	Attraction evident.
29	7/31	Tunny skin, 100 g. extracted with 200 ml. dist. water, filtered through cheesecloth: filtrate.	T	T	(X)	Slight attraction at first, then repulsion--visual?
30	7/31	Tunny blood, 150 cc. extracted with 300 ml. dist. water, filtered through cheesecloth: filtrate.	T	T	XX	Great excitement, but circling in attractive area only during 1st and 3rd periods.
31	8/1	dl-Phenylalanine, 2.5 g.	T	vW/T	-	
32	8/1	Arginine, 2.5 g.	T	vW/T	-	
33	8/1	l-Tyrosine, 2.5 g.	T	vW/T	-	
34	8/1	dl-Isoleucine, 2.5 g.	T	vW/T	-	
35	8/4	Gelatine, ca. 6 g.	T	T	-	
36	8/4	Eosin B, 0.6 g.	T	T	-	Slight repellent effect from this red dye.
37	8/4	Isoeugenol, 2.5 g.	T	T	-	

Expt. No.	Date 1952	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
38	8/4	Methylene blue, 0.6 g.	T	T	-	Slight repellent effect from this blue dye.
39	8/5	Skipjack flesh, 252 g. extracted with 350 ml. water, centrifuged 7/31, centrifugate dialyzed: dialyzate.	T	vW/T	XX	Feeding reaction, but not clear-cut attraction of controls.
40	8/5	Same as No. 39: residue from dialysis.	T	vW/T	(X)	Slight attraction in first period.
41	8/5	dl-Valine, 2.5 g.	T	vW	-	
42	8/5	l-Taurine, 2.5 g.	T	vW	-	
43	8/7	Skipjack blood, 125 ml.	T	vW/T	XXX	
44	8/8	l-Leucine, 2.5 g.	T	vW/T	-	
45	8/8	dl-Norleucine, 2.5 g.	T	vW/T	-	
46	8/8	Tunny blood, 110 ml. dialyzed with 500 ml. dist. water for 48 hours: dialyzate.	T	T	(X)	No excitation, positive reaction doubtful.
47	8/8	Same as No. 46: residue dialysis.	T	T	-	No noticeable reaction fish not acting normally?
48	8/11	Skipjack skin, 48 g. extracted with 150 ml. dist. water, centrifuged 1-1/2 hours: centrifugate (still cloudy).	T	T	X	Some attraction, probably not visual as "cloud" not apparent in tank.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
49	8/11	Aholehole, 70 g. extracted with 210 ml. dist. water: centrifugate.	T	T	X	
50	8/11	Skipjack flesh, 1000 ml. stock extract 1/	T	T	XXX	
51	8/12	dl-Serine, 2.5 g.	T	vW/T	X	Fish seemed to "follow" the path of solution.
52	8/12	Skipjack flesh, 306 g. extracted with 500 ml. water, centrifuged 8/7, centrifugate dialyzed: residue from dialysis.	T	vW/T	XX	
53	8/12	Same as No. 52: dialyzate.	T	vW/T	X	Increased time spent in area of attraction but no great excitement.
54	8/12	Skipjack flesh, 5000 ml. stock extract.	P	T	XXXX	Great excitement, no record kept.
55	8/14	Beef blood, whole, 200 ml.	T	T	-	Visual attraction at first, then strong repulsion.
56	8/15	dl-Serine, 2.5 g.	T	T	(X)	Possibly some attraction but no excitement.

1/ "Stock extract" was prepared by grinding 9 lb. of skipjack flesh, adding 10 gal. water and extracting in refrigerator. The clear, reddish supernatant liquid was used in testing.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
57	8/15	Skipjack flesh, 1000 ml. stock extract dialyzed with 850 ml. dist. water 8/11, and with 1100 ml. dist. water 8/12, removed 8/14; residue from dialysis.	T	T	XXX	During controls, some of material leaked in causing premature attraction.
58	8/15	Same as No. 57: dialyzate.	T	T	X	Positive but weak attraction.
59	8/18	Skipjack flesh, 1000 ml. stock extract, boiled for 1/2 hour: centrifugate.	T	T	(X)	Very slight attraction, perhaps visual to froth on water.
60	8/18	Same as No. 59: residue.	T	T	-	
61	8/18	Beef blood plasma, 280 ml.	T	T	-	
62	8/18	Albumen, 100 g.	T	T	-	
63	8/18	Skipjack flesh, 1000 ml. stock extract.	T	T	-	Possibly a slight response? Fish not responsive, throwing doubt on all 8/18 experiments.
64	8/18	Skipjack flesh, 1000 ml. stock extract.	P	T	XX	5-minute timing intervals.
65	8/18	Skipjack flesh, 500 ml. stock extract.	P	T	XXX	" " "

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
66	8/18	Skipjack flesh, 250 ml. stock extract.	P	T	XXX	Mistake in timing, first interval.
67	8/19	Skipjack flesh, 250 ml. stock extract.	P	T	XX	
68	8/19	Skipjack flesh, 1500 ml. stock extract, centrifugate ppted. with 10% HCl, centrifuged, neutralized: "non-protein fraction".	P	T	X	Slight delay in reaction.
69	8/19	Same as above, residue from second centrifuging, neutralized: "protein fraction".	P	T	XX	Good feeding reaction.
70	8/19	Skipjack blood, 50 ml.	P	T	XXX	Yellowfin also reacted strongly.
71	8/19	Anethol, 10 ml. dispersed with Tergitol.	P	T	-	Curiosity to smell in first period--licorice-like.
72	8/20	Skipjack flesh: 250 ml. stock extract.	P	T	XXX	
73	8/20	Skipjack flesh: 500 ml. stock extract, heated at 85 °C for 1/2 hour.	P	T	XX	
74	8/20	Whole beef blood, 250 ml.	P	T	-	Repellent effect.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
75	8/20	Skipjack flesh, 500 ml. stock extract, heated at 69° C. for 1/2 hour, centrifuged: washed residue.	P	T	X	No great excitment.
76	8/20	Same as No. 75: centrifugate.	P	T	XX	Feeding reaction.
77	8/20	Skipjack flesh, 500 ml. stock extract, boiled 1/2 hour: filtrate.	P	T	XX	Feeding reaction, yellow-fin participated.
78	8/21	Skipjack flesh, 1000 ml. stock extract, boiled 1/2 hour, centrifugate.	P	T	XX	
79	8/21	Same as No. 78: residue.	P	T	X	Very weak but positive reaction.
80	8/21	Skipjack flesh, 250 ml. stock extract.	P	T	X	Weak but positive.
81	8/21	Skipjack flesh, 250 ml. stock extract, old.	T	T	XXX	Fish in tank responsive after their rest.
82	8/21	Skipjack flesh, 250 ml. stock extract, new.	T	T	XX	"
83	8/22	Skipjack flesh, 600 ml. stock extract, boiled 15 min., centrifugate saturated with NaCl stood overnight, centrifuged: centrifugate.	P	T	XXX	Delayed reaction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
84	8/22	Skipjack flesh, 600 ml. stock extract, boiled 15 min., centrifugate boiled one hour: centrifugate of second boiling.	P	T	XXX	Good feeding reaction.
85	8/22	Skipjack flesh, 600 ml. stock extract, boiled 15 minutes: centrifugate.	P	T	XX	Only 5 of 11 fish participating.
86	8/22	Part of No. 83: 100 ml. boiled, salted centrifugate.	T	T	XXX	Verifies No. 83.
87	8/22	Skipjack flesh, 100 ml. stock extract (putrefied).	T	T	X	Very slight reaction.
88	8/25	Same as No. 83, centrifuge residue.	P	T	-	
89	8/25	Animal Protein Factor (equivalent in growth effect to vitamin B_{12}), 50 g.	P	T	-	
90	8/25	Skipjack flesh, 1000 ml. stock extract, dialyzed 9/21 with 2 liters dist. water, changed once: dialyzate.	P	T	X	Slight reaction: feeding reaction.
91	8/25	Same as No. 90: residue after dialysis.	P	T	XX	Better reaction, fish fed heavily previous day and not too responsive; yellowfin also reacting.
92	8/25	Animal Protein Factor, 25 g.	T	T	-	Visual attraction only.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
93	8/25	Skipjack flesh, 300 ml. stock extract (putrefied).	T	T	X	Reaction apparent but weak.
94	8/26	Ulua blood, 65 ml. plus 5 cc. 4% citric acid.	P	T	X	Positive though weak.
95	8/26	Skipjack blood, 75 ml. plus 5 cc. 4% citric acid	P	T	XX	Stronger; feeding reaction.
96	8/26	Ulua flesh, 100 g. extracted with 300 ml. dist. water: centrifugate.	P	T	X	Positive but weak, lasted only short time.
97	8/26	Skipjack flesh, 250 ml. stock extract.	P	T	XX	Yellowfin also reacted, feeding reaction.
98	8/26	Barracuda flesh, 100 g. extract with 300 ml. dist. water: centrifugate.	P	T	(X)	Very slight reaction noted.
99	8/26	Aholehole whole, 250 g. extracted with 500 ml. dist. water, supernatant liquid boiled: centrifugate.	P	T	XXX	Great excitement, yellowfin reacting.
100	8/26	Same as No. 99: residue from centrifuging upper part, mostly skin, etc.	P	T	XXX	Great excitement in 2nd and 3rd periods.
101	8/28	dl-Serine, 3 g.	P	T	?	Fish showed curiosity, but no speeding up or noticeable attraction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
102	8/28	l-Asparagine, 3g.	P	T	-	As above, sensed but no noticeable attraction. Fish erratic.
103	8/28	Arginine, 3 g.	P	T	-	As above.
104	8/28	dl-Serine, 1 g.	T	T	-	Absolutely no attraction.
105	8/28	Aholehole, whole 250 g. extracted with 500 ml. dist. water, not boiled: centrifugate.	T	T	X	Slight attraction.
106	8/28	Skipjack flesh, 250 ml. stock extract.	T	T	XX	
107	8/28	Skipjack flesh, 100 ml. of boiled, salted, stock extract, concentrated to about 1/3 original volume by boiling.	T	T	XXX	
108	8/29	dl-Serine, 3 g.	P	T	-	No reaction whatsoever.
109	8/29	Creatine, 3 g.	P	T	-	" " "
110	8/29	Nucleic acid, 3 g.	P	T	-	" " "
111	8/29	Skipjack flesh, 250 ml. stock extract.	P	T	X	Reaction positive but not strong.
112	8/29	Skipjack flesh, 3000 ml. stock extract, siphoned in over period of 48 min. to set up gradient.	P	T	XXXX	Strong and persistent reaction and attraction, fish running up gradient; time in first 1/10 of tank.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
113	9/2	Skipjack flesh, 2 liters stock extract; boiled; centrifuged; centrifugate treated with NaCl; centrifuged; centrifugate boiled to residue (plus NaCl); dissolved in sea water.	P	N	XX	Obvious reaction with feeding; tunny fighting with yellowfin.
114	9/2	Skipjack flesh, 1 liter stock extract; residue of dialysis boiled to gummy residue: portion soluble in 95% alcohol.	P	N	X	Strong in first period only.
115	9/2	Same as No. 114: portion insoluble in 95% alcohol.	P	N	(X)	Slight reaction in upper tenth of pond?
116	9/2	Same as No. 114: white crystals insoluble in 95% alcohol.	P	N	X	Definite reaction with feeding.
117	9/2	Skipjack flesh, 250 ml. stock extract.	P	N	XXX	Most vigorous reaction of the day.
118	9/4	Skipjack flesh, stock extract, 1000 ml. dialyzate boiled down to 10 ml.	P	vW	XXX	Yellowfin also reacted strongly.
119	9/4	Tuna fish meal, 10 g. boiled with 250 ml. water for 10 min.: filtrate.	P	vW	XX	
120	9/4	Tuna fish meal, 10 g. suspended in 250 ml. water, not boiled.	P	vW	XX	Perhaps not as strong a reaction as in No. 119.
121	9/4	Skipjack flesh, 2000 ml. stock extract, centrifugate salted, boiled to 10 g. residue, redissolved in water.	P	vW	X	Tide high, water murky, observation difficult.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
122	9/4	Skipjack flesh, 250 ml. stock extract: filtrate.	P	vW	XX	Tide high, water murky, observation difficult.
123	9/9	Skipjack flesh, 1000 ml. stock extract, dialyzate boiled to dryness, residue extracted with absolute alcohol.	P	vW	XX	Yellowfin also reacted.
124	9/9	Same as No. 123, alcohol insoluble portion.	P	vW	(X)	Doubtful; no reaction from yellowfin.
125	9/9	Skipjack flesh, 1000 ml. stock extract, boiled; residue (watery solution) purified by boiling with activated carbon, 1 g. gummy residue redissolved.	P	vW	X	
126	9/9	Skipjack viscera, 150 ml. juices, preserved with 2% SO_2 (H. T. P.)	P	vW	XXXX	Very strong reaction by both species.
127	9/9	Glycyl-glycine, 1 g.	P	vW	-	
128	9/9	Skipjack flesh, 250 ml. stock extract: filtrate.	P	vW	(X)	High tide; observation difficult.
129	9/11	Lecithin (animal), 2.5 g.	P	vW	-	
130	9/11	Skipjack flesh, 1000 ml. stock extract, evaporated, boiled with 5 g. activitated carbon, filtered, treated with 5 g. activated Al, evaporated to dryness; dark gum redissolved.	P	vW	X	

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
131	9/11	Ambergris, 2.5 g.	P	vW	-	
132	9/11	Pregnenolone, 1 g.	P	vW	-	
133	9/11	Skipjack flesh 1000 ml. stock extract, evaporated, boiled with 5 g. activated carbon, filtered, treated with 5 g. anion exchange resin, evaporated to light gum, redissolved.	P	vW	XXX	Strong reaction in beginning, yellowfin also participated.
134	9/11	Skipjack flesh, 1000 ml. stock extract, evaporated, boiled with 5 g. activated carbon, evaporated to dryness, treated with 5 g. cation exchange resin, evaporated to dark gum, redissolved.	P	vW	XX	Reaction not as strong as No. 133, however, pump stopped and had to be repaired so that beginning of reaction not observed well.
135	9/11	Skipjack flesh, 250 ml. stock extract.	P	vW	XXXX	Very strong reaction, with feeding manifestation.
136	9/16	Skipjack flesh extracted with equal part water, 50 ml. filtrate, frozen, thawed.	P	vW/T	XXXX	
137	9/16	Skipjack viscera extracted with equal part water, 50 ml. filtrate, frozen, thawed.	P	vW/T	XXXX	About same as No. 136, quite strong.
138	9/16	Skipjack flesh extracted with equal part water, 50 ml., boiled, frozen, thawed.	P	vW/T	X	

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
139	9/16	Skipjack viscera, extracted with equal part water, 50 ml. boiled, frozen, thawed.	P	vW/T	XXX	
140	9/16	Skipjack flesh extracted with equal part water, 50 ml. preserved at RT with 2% SO_2.	P	vW/T	XXX	
141	9/16	Skipjack viscera extracted with equal part water, 50 ml. preserved at RT with 2% SO_2.	P	vW/T	XX	Good in 1st period but died away quickly.
142	9/18	Skipjack flesh extracted with equal part water, 50-75 ml. boiled to dryness, extracted with petroleum ether (nothing removed), extracted with acetone (nothing removed), and alcohol; alcohol soluble part treated with absor. carbon and passed through cation column: portion not absorbed.	P	T	XXX	Feeding reaction.
143	9/18	Same as No. 142; portion absorbed on cation exchange resin and eluted with 0.15N NH_4OH.	P	T	-	
144	9/18	Skipjack viscera extracted with equal part water, 50 ml. treated with 2% H_2SO_4, kept at RT.	P	T	XX	Feeding reaction.
145	9/18	Same as No. 144, 50 ml. treated with 2% H_3PO_4, kept at RT.	P	T	X	
146	9/18	Same as above, 50 ml. frozen, thawed before using.	P	T	X	Feeding reaction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
147	9/18	Skipjack flesh, 500 g. extracted with 750 ml. alcohol for 1/2 hour, 90 ml. clear, rosy-colored centrifugate.	P	T	XX	Delayed reaction.
148	9/23	Skipjack flesh, as above, extracted for 2 days with alcohol, 340 g. residue from centrifuging washed with alcohol, washed with water, extracted with 240 g. water since 9/19: centrifugate.	P	T	XXX	Feeding reaction.
149	9/23	Skipjack flesh extracted with equal parts alcohol, 100 ml. centrifugate passed through activated alumina: portion not absorbed.	P	T	XX	Feeding reaction.
150	9/23	Same as No. 149: portion absorbed on activated alumina, eluted with water.	P	T	XXX	Slightly better than No. 149; feeding reaction.
151	9/23	Skipjack flesh extracted with equal parts alcohol, 100 ml. centrifugate passed through zeolite: portion not absorbed.	P	T	XX	Feeding reaction.
152	9/23	Same as No. 151: portion absorbed on zeolite eluted with water.	P	T	XX	Slightly weaker than No. 156; feeding reaction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
153	9/25	Skipjack flesh, 100 ml. alcohol extract adsorbed on activated charcoal: portion adsorbed, eluted with water, clear.	T	T	X	Reaction at first only.
154	9/25	Same as No. 153: portion not adsorbed (yellowish alcohol solution).	T	T	XXX	Feeding reaction.
155	9/25	Skipjack flesh, 400 ml. alcohol extract from No. 147; centrifuged; centrifugate ev. to dryness at R. T.; brown gum redissolved in 95% alcohol; passed through activated aluminum column: filtrate evap. to dryness and brown gum redissolved in water.	T	T	X	
156	9/25	Same as No. 155: eluate evap. to dryness and redissolved in water.	T	T	XXX	Most of fish did not enter attraction area until 3rd period; great feeding reaction.
157	9/25	Methionine, 0.5 g.	T	T	-	Fish exhibit curiosity?
158	9/25	Alpha Ionone, 2 ml.	T	T	-	

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
159	9/30	Skipjack flesh, 600 g., extracted with 1000 ml. alcohol; 100 ml. treated with activated charcoal till clear, and passed through charcoal column; eluted with acetone; ca. 10 mg. small white crystals in eluate dissolved in water.	P	T	X	Weak, no feeding reaction.
160	9/30	Same as No. 159: white ppte. in alcohol residue, not adsorbed on charcoal, dissolved in water.	P	T	-	No obvious reaction.
161	9/30	Same as No. 159: portion not adsorbed on charcoal (minus white ppte. of No. 160).	P	T	XX	Feeding reaction.
162	9/30	Alcohol extract (No. 159), 100 ml., adsorbed on activated alumina: portion not adsorbed.	P	T	XX	Slightly better reaction than No. 161.
163	10/2	Skipjack flesh, 200 g. extracted once with 500 ml. alcohol (48 hr.); filtered: reddish clear filtrate.	P	T	XXXX	Great excitement, feeding reaction lasting 15 min.
164	10/2	Same as No. 163; residue extracted 2nd time with 500 ml. alcohol; filtered; residue extracted third time with 700 ml. water; filtered: clear colorless filtrate.	P	T	XX	Fish didn't enter field until end of 2nd period; then very strong feeding reaction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
165	10/2	Same as No. 162: yellowish, slightly cloudy portion adsorbed on alumina and eluted.	P	T	XXX	Great excitement and feeding reaction.
166	10/7	Vitamin B_{12}, 5 mg. dissolved in water, reddish color.	P	T	-	Possibly sense material, but no noticeable reaction.
167	10/7	Skipjack flesh, 50 g., extracted with 50 ml. alcohol; adsorbed on charcoal: white crystals in eluate re-dissolved in water.	P	T	-	Fish surfaced, but no other noticeable reaction.
168	10/7	Pineapple juice, 160 ml.	P	T	-?	Fish sensed it; surfaced and turned back; no feeding.
169	10/7	Skipjack flesh, 600 g., extracted twice with 600 ml. alcohol; extracted a third time with water: 500 ml. centrifugate from water extraction.	P	T	XX	Fish didn't enter field until 2nd period; some feeding reaction but not as much as in No. 164.
170	10/9	Skipjack flesh, 100 g., extracted twice with alcohol; further extracted with alcohol for 14 hours in Soxhlet; residue extracted 12 hours with 200 ml. dist. water; centrifuged: clear colorless centrifugate.	P	T	(X)	Very slight reaction, no feeding.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
171	10/9	Alcohol extract from No. 170, adsorbed on charcoal; eluted with acetone; 20 mg. white needle-like crystals dissolved in water.	P	T	(X)	Slight sensing? No surfacing, no feeding.
172	10/9	"Alamask" (DuPont aromatic R-200.611), 2 ml. dispersed with Tergitol and emulsified in water.	P	T	-	
173	10/9	Skipjack flesh, stock solution, 250 ml. (old, deteriorated, weakened by successive freezing and removal of unfrozen solution).	P	T	X	Positive reaction in first and second period, but not thereafter.
174	10/11	"Slik", 10 ml.; (commercial fish attractant).	P	vW	-	Has cod liver oil smell. Fish noticed it but not noticeably attracted.
175	10/11	Skipjack flesh, 100 g., extracted with alcohol in Soxhlet; extracted with petrol ether; evaporated; residue dissolved in abs. alcohol and dispersed in water with tergitol.	P	vW	X	Slight attraction, no feeding reaction, speed decreased after 10 min.
176	10/11	Acetyl tryptophane, 1.5 g. dissolved in water.	P	vW	-	

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
177	10/16	Skipjack flesh, 200 g., extracted with alcohol; evap. to dryness; fatty substances dissolved in pet. ether; pet. ether evaporated; residue taken up with abs. alcohol, dispersed in water with Tergitol: white emulsion.	P	T	X	Definite speeding up and surfacing, but rather weak reaction.
178	10/16	Skipjack flesh, 250 g., extracted with alcohol; passed through charcoal column; evap. to dryness and extracted with pet. ether; passed through Duolite C-3 Cation exchange resin: clear colorless portion not adsorbed on cation resin.	T	T	X	Slight speeding up noticed. Experiment disturbed by rain squall.
179	10/16	Same as No. 178, but passed through Duolite A-3 Anion exchange resin: clear, yellowish portion not adsorbed on anion resin.	P	T	X	Good reaction for first period, but died off quickly. Rainstorn disturbed experiment.
180	10/21	Skipjack flesh, 340 g. extracted for 9 days with 340 ml. alcohol; centrifugate.	P	T	XX	Reaction lasted for 3 periods, surfacing and feeding.
181	10/21	Same as No. 178: portion adsorbed on cation exchange resin and eluted with 5% H_2SO_4: colorless eluate.	P	T	(X)	Sensed material but very slight reaction, if any.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
182	10/21	Same as No. 179: portion adsorbed on anion exchange resin and eluted with 5% NaOH: yellowish eluate.	P	T	XX	Good reaction, including surfacing and feeding.
183	10/21	Skipjack flesh, 250 g. extracted with alcohol; charcoal treated; fat extracted; evap. to dryness in vacuum: portion of residue insoluble in 95% alcohol but soluble in water, purines removed as Ag salts: yellowish sol.	P	T	XX	Good reaction including surfacing and feeding.
184	10/21	Same as No. 183: portion of residue soluble in 95% alcohol; purines removed as Ag salts: yellowish solution.	P	T	X	An obvious speeding-up in first three periods.
185	10/25	Skipjack flesh, 700 g., extracted with alcohol, conc. under vacuum; fat out with pet. ether, ether removed under vacuum; passed over charcoal; adsorbed on anion exchange resin Duolite A-3; eluted with 10% NH_4OH: 1st portion of eluate.	P	vW	XX	Abudefduf also left coral and reacted.
186	10/25	Same as No. 185: 2nd portion of eluate.	P	vW	X	Tuna swam slowly, no Abudefduf reaction.
187	10/25	Same as No. 185: 3rd portion of eluate.	P	vW	-	Seemed to note substance only during 1st minute.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
188	10/25	Trimethylamine oxide, 1.5 g. in water.	P	vW	-	
189	10/25	Peptone "I" (Nutr. Biochem.), 1.5 g. in water.	P	vW	-	
190	10/25	l-Histidine monohydrochloride, 1.5 g. in water.	P	vW	-	
191	10/25	l-Glutamic acid, 1.5 g. in water.	P	vW	-	
192	10/28	Acetylcholine chloride, 100 mg. in water.	P	T	-	Sensed material but no surfacing or feeding reaction.
193	10/28	Skipjack flesh, 350 g., extracted with alcohol; fat out with pet. ether; through charcoal column; through anion exchange column; portion held on column and eluted with NH_4OH; evaporated in vacuum; residue redissolved in water and nitrogen compounds ppted. with phosphotungstic acid; filtrate.	P	T	XX	Good reaction with surfacing and feeding.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
194	10/28	Skipjack flesh, 700 g., second alcohol extraction; through charcoal column; through anion exchange column; portion eluted from column with water: whitish liquid.	P	T	XX	Fish late in entering area, but then showed good reaction, with feeding.
195	10/28	Same as No. 194: portion eluted from column with 95% alcohol.	P	T	-	No reaction at any time.
196	11/8	Skipjack flesh, extracted with alcohol; treated with lead acetate; filtered; fat removed from filtrate with pet. ether; lead removed with H_2S, and H_2S removed in vacuum; adsorbed on anion resin and eluted with 5% NH_4OH: eluate neutralized with HCl.	P	vW	-	No noticeable reaction; visibility poor.
197	11/8	Same as No. 196 to removal of H_2S: filtrate.	P	vW	XXXX	Tuna showed surfacing and feeding reaction; also Abudefduf; visibility poor.
198	11/8	Histamine diphosphate, 8 mg., free base liberated with NH_4OH.	P	vW	-	Abudefduf may have showed a slight reaction; visibility poor.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
199	11/18	Skipjack flesh, 80 g., extracted with water one month previously: held in reefer.	P 2/	T	XXX	Good reaction with surfacing.
200	11/18	Same as No. 196, i.e. leaded, de-leaded, fat removed, passed through anion column twice: filtrate from anion column.	P 2/	T	-	No reaction, except perhaps a slight sensing of material?
201	11/18	Same as No. 196; water eluate from No. 200 evaporated to dryness and treated with abs. alcohol: residue soluble in alcohol.	P 2/	T	XX	Fair reaction with surfacing and feeding.
202	11/18	Same as No. 201: residue insoluble in alcohol but soluble in water.	P 2/	T	-?	May be slight attraction?
203	11/18	Skipjack flesh extracted with water, same as No. 199.	P 2/	T	XXX	Good reaction.
204	11/22	Same as No. 201: weak NH_4OH eluate evaporated to dryness, treated with abs. alcohol: residue soluble in alcohol.	P 2/	vW	-	No reaction.
205	11/22	Same as No. 204: residue insoluble in alcohol but soluble in water.	P 2/	vW	-	
206	11/22	Same as No. 201: eluate at pH 3-4, neutralized.	P 2/	vW	-	

2/ Material thrown from tower; pump not working.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
207	11/22	Skipjack flesh, extracted with water, ca. 100 ml.	P[2/]	vW	XXXX	Good reaction.
208	12/6	Same as No. 196: first portion of water eluate from anion column, basic in nature.	P	vW	X	Swimming speed increased, no feeding reaction.
209	12/6	Same as No. 208: third portion of water eluate from anion column, still basic in nature.	P	vW	-	
210	12/6	Same as No. 208: fourth portion of water eluate from anion column, starting to become acidic.	P	vW	-	
211	12/9	Skipjack flesh, extracted with alcohol; treated with barium acetate; filtered; filtrate treated with H_2SO_4 to ppte. $BaSO_4$ and this left in suspension: filtrate.	P	T	-?	Visibility poor; no apparent reaction, although fish did not enter field until after expt. was over.
212	12/9	Same as No. 211: residue treated with NHO_3 and barium ppted. as $BaSO_4$: filtrate.	P	T	-	Visibility ok.
213	12/9	Same as No. 196, but new anion exchanger (Amberlite IRA-400) used: first water eluate.	P	T	XX	Surfacing and feeding reactions.
214	12/9	Same as No. 213: second water eluate.	P	T	-	May have been a slight sensing.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
215	12/9	Skipjack flesh, 1800 g. third alcohol extract; treated with tannic acid (protein out); treated with $PbAc_2$ (protein and tannic acid out); treated with H_2SO_4 (Pb out); treated with phosphotungstic acid (purines out); treated with Ba (phosphotungstic acid out); treated with SO_4 (Ba out).	P	T	X	Very weak, if any, reaction.
216	12/9	Skipjack flesh, 1800 g. first alcohol extract, 100 ml.; treated with phosphotungstic acid; filtered; phosphotungstic acid removed with barium acetate; passed through cation column (Amberlite IR-120) to remove barium: filtrate from column.	P	T	X	Very weak. Reaction about the same as No. 215.
217	12/11	Fresh tuna stickwater from H. T. P. (high oil content): 200 ml.	P	T	XXX	Reaction good; feeding and surfacing.
218	12/11	Same as No. 216, except barium chloride used: filtrate from column, neutralized.	P	T	-	Material introduced too soon by accident, but no reaction.
219	12/11	Skipjack whole ground viscera (except gonads), preserved in 2% SO_2, self-digested; prepared 9/25/52 by H. T. P.: 200 ml. brown mixture from can.	P	T	XX	Fair reaction with feeding and surfacing.
220	12/11	Skipjack whole viscera, steamed at 20 lb. press.; preserved in 3% PO_4 in bottle; prepared 5/26/52 by H. T. P.; yellowish supernatant liquid, 125 ml.	P	T	XXX	Good reaction which was renewed when pipe was flushed after expt.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
221	12/11	Skipjack whole ground viscera, preserved in 3% SO_2 in bottle; prepared 5/26/52 by H. T. P.; yellowish supernatant liquid, 125 ml.	P	T	XXXX	Surfacing, speeding up, best feeding reaction yet observed.
222	12/11	Same as No. 217: fresh tuna stickwater, 200 cc. mixed with fluorescein dye.	P	T	XXX	Good reaction which could be traced with dye.
223	12/13	Skipjack flesh, 1800 g., second alcohol extract, treated with phosphotungstic acid; filtered; filtrate through cation (Amberlite IR-120) column; filtrate through anion (Amberlite IRA-400) column: first water eluate.	P	vW	-	May have sensed material at beginning.
224	12/13	Same as No. 223, but carried only through phosphotungstic acid precipitation: filtrate.	P	vW	XXXX	Tunny followed material when it drifted out through gates; other fish also reacted.
225	12/13	Same as No. 216: filtrate from cation column neutralized.	P	vW	XX	Although reaction not vigorous it was positive.
226	12/16	Skipjack viscera self-digested and preserved in 2% SO_2 (same as No. 219); 200 ml. extract plus 200 ml. 95% alcohol adjusted to pH 9 with NH_4OH; filtered; centrifuged to remove crystals: centrifugate.	P	T	X	A poor reaction, no surfacing or feeding (cf. No. 219).

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
227	12/16	Same as No. 226: crystals, residue from centrifuging, dissolved in water.	P	T	-	
228	12/16	Skipjack viscera (same as No. 219),200 ml. water added; boiled; 200 ml. water and 1100 ml. 95% alcohol added; coagulation; filtered: filtrate, pH 7.	P	T	-	No noticeable reaction?
229	12/16	Same as No. 219.	P	T	(X)	A slight reaction when fish finally entered field in 4th period.
230	12/16	Same as No. 219 (repeat of No. 229).	P	T	X	Some reaction, but no feeding.
231	12/16	Furfuryl mercaptan 10% (Du Pont Aromatics No. 2295), dispersed in water with Tergitol, 1.5 ml.	P	T	?	The material was sensed; fish surfaced, and kept returning to area. No feeding reaction noted.
232	12/27	Skipjack viscera prep. (same as No. 219), 200 ml., treated as in No. 228; filtrate adjusted to pH 2 with H_2SO_4; phosphotungstic acid added; filtered; filtrate treated with $Pb(Ac)_2$; filtered; filtrate passed through strong cation exchanger (Amberlite IR-120): unadsorbed portion.	P	vW	(X)	Slightly excited, milling around inlet for short period; very weak reaction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
233	12/27	Skipjack viscera prep. (same as No. 219), 200 ml.; 400 ml. 95% alc. added; stood 1/2 hr., filtered; phosphotungstic acid added to filtrate after adjusted to pH 2 with HCl; filtered; $Pb(Ac)_2$ added to filtrate; filtered; filtrate passed through strong cation exchanger (Amberlite IR-120); adjusted pH unadsorbed portion to pH 4; passed through strong anion exchanger (Amberlite IRA-400); unadsorbed portion.	P	vW	-	No reaction.
234	12/27	Skipjack viscera prep. (same as No. 219); treated as in No. 233; adsorbed portion from anion column.	P	vW	-	No reaction.
235	12/27	Skipjack viscera prep. (same as No. 219), 400 ml.; 1000 ml. 95% alc. added; stood 1/2 hr., filtered: filtrate.	P	vW	XXX	Strong reaction with feeding.
236	12/27	Skipjack viscera prep. (same as No. 219), 400 ml.; cooked under pressure for 1/2 hr.; filtered: filtrate.	P	vW	X	Positive but weak attraction; no feeding reaction.
237	12/30	Skipjack viscera prep. (same as No. 219); treated same as No. 233: portion unadsorbed on anion column.	P	T	-	No reaction.
238	12/30	Skipjack viscera prep. (same as No. 219); treated same as No. 234: portion adsorbed on anion column.	P	T	-	No reaction.

Expt. No.	Date 1952/53	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
239	12/30	Bigeye flesh, 100 g. plus 140 ml. water extracted, filtered: filtrate.	P	T	XX	Speeding, surfacing and feeding; visibility poor.
240	12/30	Bigeye flesh, 100 g. plus 140 ml. water, cooked under pressure 1/2 hr., filtered: filtrate.	P	T	XX	About same as No. 239.
241	12/30	Furfuryl mercaptan, 1.0 ml., dispersed with Tergitol in water.	P	T	(X)	Surfacing, speeding but no feeding, attraction?
242	1/6	Adenosine, 1.0 g., dissolved in water just prior to testing.	P	T	-	No reaction.
243	1/6	Adenosine triphosphate, disodium salt, 95% 0.1 g., dissolved in water just prior to testing.	P	T	(X)	No speeding or feeding, but continuous turning back, a sensing of material?
244	1/6	Adenylic acid (muscle), 0.1 g., dissolved water (not very soluble).	P	T	-	No reaction.
245	1/6	Adenosine diphosphate, barium salt, 0.1 g., dissolved in 0.1N HCl and Ba ppted. with 6N H_2SO_4 just prior to testing.	P	T	(X)	Speeding and turning back; a sensing of material?
246	1/6	Bigeye flesh, alcohol extract, leaded and de-leaded through anion exchanger; adsorbed portion eluted and evap. to dryness; re-dissolved in abs. alc. and fractionated on alcohol anion column; adsorbed portion eluted with 250 ml. water; 10 ml. fractions collected; fractions 1-6.	P	T	(X)	Turning back, but no surfacing or feeding; visibility poor.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
247	1/13	Same as No. 246; fractions 7-13 incl.	P	T	?	Fish came into field in 1st period but then stayed down-stream for 3 periods. Appeared to notice material when in field in 5th period.
248	1/13	Same as No. 246; fractions 14-26 incl.	P	T	-	No reaction.
249	1/13	Coumarin, 3 g. (DuPont Aromatics R. 1697), dissolved in water.	P	T	-	No reaction.
250	1/13	Methyl anthranilate, 2 ml. (DuPont Aromatics R. 1581), dispersed with Tergitol in water.	P	T	-	No reaction.
251	1/13	Phenyl acetic acid, 2 g. (DuPont Aromatics R. 7618) dissolved in water.	P	T	-	No reaction.
252	1/13	Bigeye flesh, 125 g. extracted with water; filtered; filtrate.	P	T	XX	Surfacing speeding, milling, and feeding reaction.
253	1/13	Meat flavor, 1 ml. (SA. 6321), dissolved in water.	P	T	(X)	Seemed to sense material; kept turning back, feeding reaction.
254	1/17	Adenosine triphosphate, disodium salt (same as No. 243).	P	vW	-	No reaction.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
255	1/17	Adenosine diphosphate, barium salt (same as No. 245).	P	vW	-	No reaction.
256	1/17	Bigeye flesh, 1800 g. extracted with 1000 ml. 95% alcohol; filtered; filtrate treated with $Pb(Ac)_2$ and Pb removed on strong cation exchanger; unadsorbed portion adjusted to pH-4 with NH_4OH and passed through strong anion exchanger; adsorbed portion eluted with water, evaporated, re-dissolved in abs. alc.; heated to boiling; charcoal added and filtered; 1/6 of filtrate (equiv. to 200 g. flesh).	P	vW	-	No reaction.
257	1/17	Bigeye flesh, 1000 g. extracted with 1000 ml. alcohol, $Pb(Ac)_2$ added; filtered filtrate put through cation exchanger; unadsorbed portion filtered to remove ppte.; filtrate through anion exchanger and eluted with water; 1/2 adsorbed portion (equiv. to 500 g. flesh).	P	vW	(X)	A little excitement at beginning but no feeding nor attraction.
258	1/20	Skipjack viscera prep. (HTP)[3/], pepsin digested, preserved in 2% $NaHSO_3$, 200 ml.	P	T	-	No reaction.
259	1/20	Bigeye flesh, 125 g., extracted with water, filtered: filtrate.	P	T	(XX)	Characteristic reaction with feeding.

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Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
260	1/20	Skipjack viscera prep. (HTP) pepsin digested, 60 ml. (same as No. 258)	P	T	(X)	Possibly a slight reaction?
261	1/20	Same as No. 268 and 269; remainder of unadsorbed portion from cation column put through strong anion exchanger: unadsorbed portion equivalent to 200 g. flesh.	P	T	-	No reaction.
262	1/20	Same as No. 261: adsorbed portion on anion column eluted with 200 ml. water and tested, equivalent to 200 g. flesh.	P	T	-	No reaction or very slight.
263	1/22	Skipjack viscera prep. (HTP), pepsin digested 200 ml. (same as No. 258).	P	T	-	No reaction.
264	1/22	Skipjack viscera prep. (HTP), steam cooked (1 hr/10 lb.) filtered; clear yellow filtrate preserved in 2% $NaHSO_3$: 200 ml. tested.	P	T	XX	Very strong feeding reaction.
265	1/22	Same as No. 256, except alcohol evaporated in vacuum desicator: crystals and sludge re-dissolved and tested (equiv. to 700 g. flesh).	P	T	-	No reaction, but fish erratic in behavior.
266	1/22	Bigeye flesh, 1168 g. extracted with 95% alcohol and filtered; filtrate treated with $Pb(Ac)_2$; filtered; filtrate equiv. to 200 g. flesh treated with NaCl (ppte. not removed) and tested.	P	T	XXX	An excellent reaction, with feeding.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
267	1/22	Same as No. 266; except filtrate equivalent to 200 g. flesh treated with NaCl, filtered, and filtrate heated to boiling for 30 min.	P	T	(X)	Possibly a weak reaction.
268	1/22	Same as No. 266; remainder of filtrate put through strong cation exchanger; unadsorbed portion equivalent to 200 g. flesh tested (pH not adjusted).	P	T	?	No reaction except perhaps in first two periods when first turned back.
269	1/22	Same as No. 268, except unadsorbed portion was adjusted to pH-5 to 7 with dil. NH_4OH, equiv. to 200 g. flesh.	P	T	X	A positive but weak reaction; no feeding.
270	1/30	Adenosine diphosphate, barium salt (same as No. 240).	P	T	-	No reaction; pump went off.
271	1/30	Adenosine triphosphate, disodium salt (same as No. 238).	P	T	-	No reaction.
272	1/30	Same as No. 269, but equivalent to 100 g. flesh, pH adjusted to 7 with NH_4OH.	P	T	X	Speeding and attraction, but no feeding.
273	1/31	Bigeye flesh, extracted with 95% alc., $Pb(Ac)_2$ added to filtrate; filtered; clear filtrate treated with NaCl and heated in water bath for 30 min., tested (equiv. to 400 g. flesh, partially extracted).	P	vW	XXX	Strong attraction but no feeding; visibility poor.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
274	1/31	Same as No. 273, except filtrate, after NaCl treatment put through strong cation exchanger (IR-120): unadsorbed material, equiv. to 400 g. flesh, partially extracted. (pH dropped from 7 to 3 as a result of cation treatment).	P	vW	-	No reaction; visibility poor, many ripples.
275	1/31	Same as No. 274, except unadsorbed material from cation put through a strongly basic anion exchanger (IRA-400): adsorbed material, equiv. to 400 g. flesh, eluted with 1:50 NH_4OH and tested.	P	vW	-	No reaction; visibility poor.
276	1/31	Same as No. 274, except unadsorbed material from cation put through a weakly basic anion exchanger (A-3) and eluted with 1:50 NH_4OH: adsorbed material equiv. to 400 g. flesh.	P	vW	-	No reaction, visibility poor.
277	2/5	Same as No. 272, except pH adjusted to 2 with dil. HCl; equiv. to 100 g. flesh.	P	T	-	No reaction.
278	2/5	Same as No. 274, except filtrate put through Duolite C-2 cation exchanger: unadsorbed material equiv. to 400 g. flesh (pH dropped from 7 to 3 as a result of cation treatment).	P	T	X	A weak reaction in first period.
279	2/5	Skipjack viscera prep. (HTP), same as No. 264, 200 ml.	P	T	XXX	Good reaction with feeding

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
280	2/5	Bigeye flesh extracted (2nd time) with 95% alc., filtered; filtrate treated with $Pb(Ac)_2$; filtered; filtrate acidified with dil. HCl; filtered; filtrate, equiv. to 250 g. flesh, tested.	P	T	X	A good reaction (possibility of hangover from No. 274 in pipe).
281	2/5	Same as No. 280 except final filtrate evap. to dryness over water bath and dissolved in abs. alc.: alcohol soluble portion, equiv. to 250 g. flesh.	P	T	XX	A good reaction.
282	2/5	Same as No. 280 except final filtrate adjusted to pH 9 with dil. NH_4OH, then put through Duolite A-3 anion exchanger: adsorbed portion eluted with 1:50 NH_4OH, equiv. to 500 g. flesh.	P	T	X	A positive reaction with slight feeding.
283	2/5	Same as No. 282; unadsorbed portion from anion exchanger, equiv. to 500 g. flesh.	P	T	XX	Good reaction with feeding.
284	2/10	Skipjack viscera prep. (HTP) (same as No. 219), 100 ml. "freeze-dried" (brown powder with fishy smell); dissolved in sea water.	P	T	-	No reaction.
285	2/10	Bigeye flesh extracted (3rd time) with 95% alc. filtered; filtrate treated with $Pb(Ac)_2$; filtered; filtrate treated with HCl; filtered; filtrate adjusted to pH 7, passed through IR-120 cation exchanger: unadsorbed portion (pH 2), equiv. to 250 g. flesh, tested.	P	T	-	No reaction.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
286	2/10	Same as No. 285, except unadsorbed portion from cation adjusted to pH 8 with NH_4OH, equiv. to 250 g. flesh, tested.	P	T	X	A good reaction with feeding.
287	2/10	Same as No. 285: adsorbed portions from cation exchanger of No. 280 and No. 281, eluted with 1:50 acetic acid, equiv. to 500 g. flesh, tested.	P	T	XX	Stronger reaction but not much feeding.
288	2/17	Skipjack viscera prep. (same as No. 219), 200 ml., suspended in 200 ml. 95% alc., adjusted to pH 10 with NH_4OH; filtered: filtrate.	P	T	(X)	Some surfacing and perhaps sensing, but no positive reaction.
289	2/17	Skipjack viscera prep. (same as No. 219), 200 ml., suspended in 200 ml. 95% alc., adjusted to pH 2 with conc. HCl; filtered: filtrate.	P	T	(X)	Surfacing but no other good indications of positive reaction.
290	2/17	Skipjack viscera prep. (same as No. 219), 350 ml.: untreated.	P	T	XX	Violent reaction in first 2 periods, with feeding.
291	2/21	Yellowfin flesh extracted with water (HTP) Drum No. 1 (100 lb. to 50 gl.) 5 hours, preserved with 2% $NaHSO_3$, 100 ml.	P	T	XX	Good reaction with feeding; didn't come into field at first.
292	2/28	Bigeye flesh, 500 g. extracted with 95% alc. (1st time); filtered; filtrate adjusted to pH 2 with dil. HCl tested.	P	vW	XX	Visibility poor; feeding reaction; attraction apparent.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
293	2/28	Same as No. 292 except pH-7.	P	vW	XX(X)	Somewhat stronger reaction than No. 292.
294	2/28	Same as No. 292 except adjusted to pH-10 with dil. NH_4OH.	P	vW	XX(X)	About same reaction as No. 293.
295	2/28	Skipjack viscera prep. (same as No. 219), 200 ml. treated with 200 ml. 95% alc., adjusted to pH-2 with HCl; filtered: filtrate.	P	vW	(X)	Sensing but attraction doubtful.
296	2/28	Same as No. 295, except pH-7.	P	vW	X	Definite but weak attraction.
297	2/28	Same as No. 295, except adjusted to pH-10 with dil. NH_4OH.	P	vW	X(X)	Definite but weak attraction; stronger than No. 296.
298	3/7	Bigeye flesh, extracted with 95% alc. (2nd time); filtered; filtrate adjusted to pH-3 with dil. HCl; filtered; filtrate divided into 6 equal parts (each equiv. to 250 g. flesh); Part 1, adjusted to pH-7 with dil. NaOH.	P	vW	(X)	Sensed during 1st. period, but no feeding; remained deep.
299	3/7	Same as No. 298; Part 2, adjusted to pH-10 with dil. NaOH.	P	vW	XX	Fairly strong reaction; definite attraction and feeding.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
300	3/7	Same as No. 298; Part 3, adjusted to pH 10 with dil. NH_4OH.	P	vW	(X)	Excited during 1st period only.
301	3/7	Same as No. 298; Part 4, 0.2 g. $MgCl_2$ added; made basic with dil. NH_4OH; stood overnight; filtered to remove ppte.: filtrate.	P	vW	-	No reaction.
302	3/7	Same as No. 298; Part 5, adjusted to pH 1, boiled 15 min. (to release labile PO_4); neutralized with NaOH, filtered: filtrate.	P	vW	(X)	Sensing but no great excitement; definite reaction in 1st period.
303	3/7	Same as No. 298; Part 6, adjusted to pH 1, boiled 15 min., 0.2 g. $MgCl_2$ added; adjusted to pH 9 with NH_4OH, stood overnight; filtered to remove ppte.: filtrate.	P	vW	XX	Definite attraction with feeding; fish remain deep for most part.
304	3/19	Yellowfin flesh extract (HTP-Drum No. 2; 2/24/53?); 100 lb. to 50 gal. water, extracted for 5 hours, preserved with 2% $NaHSO_3$: 200 ml.	P	T	X	Good reaction for 1st period only: no feeding.
305	3/19	Yellowfin flesh extract (HTP-Drum No. 3; 3/4/53); 100 lb. to 50 gal. water, extracted for 5 hours, preserved with 2% $NaHSO_3$: 200 ml.	P	T	(X)	Slight attraction at beginning?
306	3/19	Skipjack viscera extract (HTP-Drum No. 4; 3/13/53) 100 lb. to 5 gal. water, extracted for 5 hours, preserved with 2% $NaHSO_3$: 200 ml.	P	T	(X)	Very slight, if any attraction.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
307	3/19	Yellowfin flesh extract; same as No. 291 (HTP-Drum No. 1; 2/18/53) 100 lb. to 5 gal. water, extracted for 5 hours, preserved with 2% $NaHSO_3$: 200 ml.	P	T	X	Good reaction during 1st period only; pump off in 4th and 5th period.
308	3/19	Repeat of No. 304 (Drum No. 2); 200 ml. (thrown into pond).	P 4/	T	XXX	Very good reaction, persisting for 1/2 hour. Surfacing, milling, speeding, feeding.
309	3/19	Repeat of No. 305 (Drum No. 3); 200 ml. (thrown in).	P 4/	T	(X)	Didn't enter field until 3rd period, weak, if any, reaction.
310	3/19	Second repeat of No. 305 (Drum No. 3); 200 ml. (thrown in).	P 4/	T	X	Weak reaction.
311	3/19	Repeat of No. 306 (Drum No. 4); 200 ml. (thrown in).	P 4/	T	X	Weak reaction.
312	3/19	Repeat of No. 307, same as No. 291 (Drum No. 1); 200 ml. (thrown in).	P 4/	T	XX	Good reaction, once material sensed, with feeding.
313	4/7	Skipjack flesh, 378 g. extracted with 300 ml. water and 83 ml. alcohol; filtered; filtrate treated with $Pb(Ac)_2$; filtered; activity of filtrate adjusted to pH-2; a.m.	P 4/	T	XXXX	Violent reaction with feeding activity and fighting with Caranx.

4/ Material thrown in from tower; noise of pump distracts fish.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
314	4/7	Same as No. 313, pH 7; a.m.	P[4/]	T	XX	Material drifted rapidly to gates; sensed by Abudefduf as well as tunny.
315	4/7	Same as No. 313, pH 10; a.m.	P[4/]	T	XX	Delayed reaction with feeding activity. Caranx also reacted.
316	4/7	Same as No. 313, pH 2; p.m.	P[4/]	T	XX	Caranx also reacted; tunny dashing up and down pond.
317	4/7	Same as No. 313, pH 7; p.m.	P[4/]	T	XX	Feeding activity.
318	4/7	Same as No. 313, pH 10; p.m.	P[4/]	T	X	Weak reaction, but with some feeding activity.
319	4/11	Same as No. 313, pH 2, a.m.	P	vW	XX(X)	
320	4/11	Same as No. 313, pH 7; a.m.	P	vW	X	
321	4/11	Same as No. 313, pH 10; a.m.	P	vW	(X)	
322	4/11	Same as No. 313, pH 2; p.m.	P	vW	X(X)	
323	4/11	Same as No. 313, pH 7; p.m.	P	vW	-	Material lost through faulty hose connection at funnel.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
324	4/11	Same as No. 313, pH-10; p.m.	P	vW	(X)	Three-fourths of material lost as in No. 323.
325	4/14	Same as No. 313, pH-10; a.m.	P	T	X(X)	Little surfacing, no feeding; visibility poor, Caranx reacting.
326	4/14	Same as No. 313, pH-2; a.m.	P	T	X	Remained deep. Visibility poor.
327	4/14	Same as No. 313, pH-2; a.m.	P	T	X	"
328	4/14	Condensed herring solubles (B.C.P.)[5/], 200 ml.	P	T	O	No reaction, but fish didn't enter area after first period.
329	4/14	Same as No. 328	P	T	O	No reaction.
330	4/14	Same as No. 313, pH-10; p.m.	P	T	X	Didn't enter area until 4th period.
331	4/14	Same as No. 313, pH-2; p.m.	P	T	(X)	Sensed material but only turned back once and circled.
332	4/14	Same as No. 313, pH-7; p.m.	P	T	(X)	Slight reaction with feeding; visibility poor; raining.

5/ British Columbia Packers, Ltd.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
333	4/18	Same as No. 313, pH 10; a.m.	P	vW	(X)	
334	4/18	Same as No. 313, pH 2; a.m.	P	vW	X	
335	4/18	Same as No. 313, pH 7; a.m.	P	vW	XX(X)	Reaction strong in first period.
336	4/18	Same as No. 313, pH 10; p.m.	P	vW	-	Fish didn't enter area during test periods.
337	4/18	Same as No. 313, pH 2; p.m.	P	vW	X	
338	4/18	Same as No. 313, pH 7; p.m.	P	vW	X(X)	
339	4/21	Same as No. 313, pH 7; a.m.	P	T	XX	Slight feeding activity, Caranx also reacting.
340	4/21	Same as No. 313, pH 7; plus furfuryl mercaptan; p.m.	P	T	XX	Tunny didn't enter area until 4th period; Caranx reacting strongly.
341	4/21	Same as No. 313, pH 10; p.m.	P	T	(X)	Didn't enter area until 3rd period; speeding only.
342	4/21	Same as No. 313, pH 2; p.m.	P	T	XXX	Strong reaction with feeding activity.
343	4/25	Same as No. 313, pH 7; a.m.	P	vW	XXX(X)	

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
344	4/25	Same as No. 313, pH 10; a. m.	P	vW	X(X)	
345	4/25	Same as No. 313, pH 2; a. m.	P	vW	(X)	
346	4/25	Same as No. 313, pH 7; p. m.	P	vW	XXXX	
347	4/25	Same as No. 313, pH 10; p. m.	P	vW	XX(X)	
348	4/25	Same as No. 313, pH 2; p. m.	P	vW	XX(X)	
349	4/28	"Fish lure" (B. C. P.), 200 ml.	P	T	X	Reaction during 1st period only.
350	5/19	Skipjack viscera extract (HTP-Drum No. 5; 5/11/53), 300 ml. a. m.	P	T	X	Didn't enter until 3rd period, Caranx reacting.
351	5/19	Same as No. 350; a. m.	P	T	(X)	Caranx reacting better than tunny.
352	5/19	Frozen ground skipjack viscera (HTP-5/11/53), 1 lb. extracted for 1 hour in water, a. m.	P	T	X	Visibility poor.
353	5/19	Same as No. 352, p. m.	P 6/	T	XX	Good feeding activity.
354	5/19	Same as No. 305 (HTP-Drum No. 3 3/4/53) (drawn after sea test of 5/13/53), 500 ml.; p. m.	P 6/	T	X	Slight feeding activity.

6/ Material thrown from tower, power off.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
355	5/19	Same as No. 306 (HTP-Drum No. 4; 3/13/53) (drawn after sea test of 5/13/53); 500 ml.; p.m.	P[6/]	T	(X)	No excitement, sensing only.
356	5/19	Same as No. 352.	P[6/]	T	XX	Good reaction from both tunny and Caranx.

MATURITY AND FECUNDITY OF BIGEYE TUNA IN THE PACIFIC

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FISH AND WILDLIFE SERVICE

Explanatory Note

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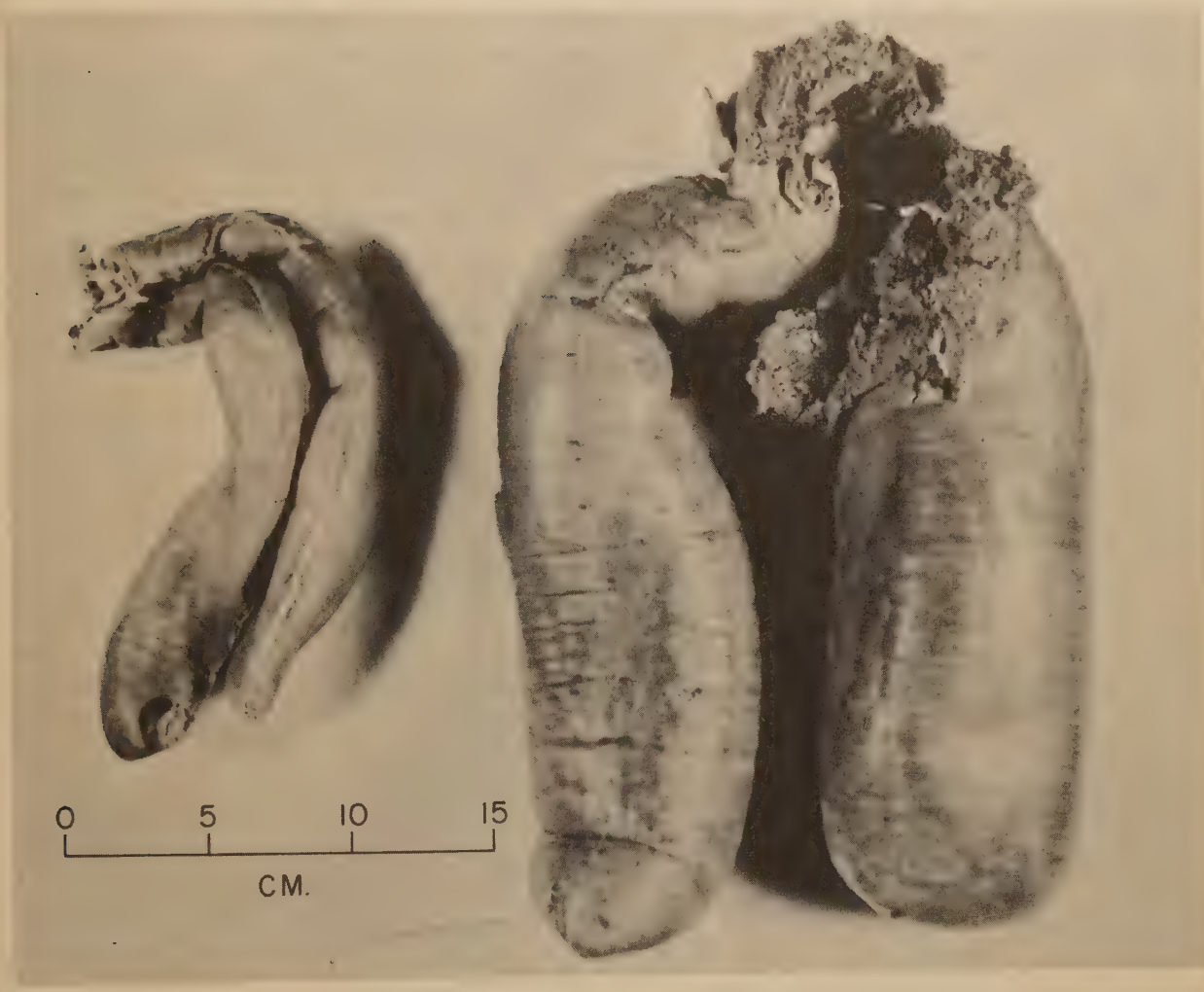

MATURITY AND FECUNDITY OF BIGEYE TUNA IN THE PACIFIC

By

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ABSTRACT

This study on bigeye-tuna spawning is based on ovaries from 700 fish collected in the central equatorial, western equatorial, and Hawaiian areas of the Pacific.

A critique on methodology is included. Egg distributions in different parts of an ovary and in the right and left members of a pair of ovaries were examined to establish a procedure which would give reliable samples for egg diameter frequencies. Two methods of measuring eggs were compared for efficiency. The error resulting from the use of ovary weight relative to body weight as a measure of the degree of ripeness was estimated.

Frequency distributions of egg diameters from maturing ovaries are multimodal with a maximum of four modes. The size at which the bigeye first spawns was found to be 14 to 20 kg. Spawning, which seems to be a year-round occurrence, takes place in the central and western equatorial areas but not in the Hawaiian area. There is evidence of more than one spawning per year with the number of eggs per spawning ranging from 2.9 to 6.3 million.

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The bigeye tuna, Parathunnus sibi (Temminck and Schlegel), is one of several commercially important tunas of the central and western Pacific. In the 7-year period of 1946 through 1952 the annual catch of the bigeye in the longline fishery of Hawaii increased from 63 tons to over 1,000 tons (Otsu 1954). The Pacific Oceanic Fishery Investigations (POFI), investigating the tuna resources of the Pacific, is interested in the commercial potentialities of this species, the first in importance in the commercial longline catches of the Hawaiian area (Otsu 1954) and second to the yellowfin in the western equatorial Pacific (Van Campen 1952).

In order to understand this increase in the catch and to evaluate the commercial potentialities of the bigeye, there is need for more information on its biology and the factors contributing to the temporal and geographic variations in its distribution. The aspects of spawning covered by this study should supply part of the required information. Knowledge of fecundity and age at maturity may help in estimates of abundance. Information on the time and place of spawning not only may explain some of the distributional variations but will facilitate the collection of the embryos and larvae which are necessary for early life history studies.

The basic method of study was the microscopic examination and measurement of eggs taken from the ovaries, as described by Clark (1934).

Papers on bigeye spawning by Shimada (1951) and Kikawa (1953) deal primarily with the time of spawning in the western equatorial Pacific. They found fish in advanced stages of maturity throughout the periods covered by their studies, June to September 1950 and June to August 1951. Keats Bank in the Marshall Islands was suspected by Kikawa to be an area of spawning concentration. Two reports on the occurrence of bigeye young may have some bearing on the time and place of spawning. In one report, Kishinouye (1919) mentioned two postlarval forms which he believed to be bigeye in the stomach of a skipjack, Katsuwonus pelamis (Linnaeus), caught at Nakasone (28°10'N., 129°15'E.) during May. In the other, Marukawa (1941) reported finding juveniles in the stomachs of yellowfin tuna, Neothunnus macropterus (Temminck and Schlegel), caught in the Tokobei area (Tobi Island, 3°N., 131°31'E.). He did not give the date of capture.

The collection of the ovaries on which this study is based was initiated by Mr. Fred June. Material from the western equatorial Pacific was collected by Messrs. K. Ego, T. Otsu, and W. Van Campen, who with other members of the POFI scientific staff also participated in collecting in the Hawaiian and central equatorial Pacific areas. Dr. A. L. Tester of the University of Hawaii and Mr. O. E. Sette, Director of POFI, made valuable suggestions concerning analytical procedures. The assistance and cooperation of these supervisors and colleagues are gratefully acknowledged.

MATERIALS AND SAMPLING METHODS

For this study ovaries taken from fish captured on longline gear were preserved in approximately 10-percent formalin. Material from the Hawaiian area was obtained at the auction room of the Kyodo Fishing Company, Ltd., where most of the catch of the Honolulu longline fleet was sold. Here the ovaries were taken from fish that had been kept on ice for as long as 3 weeks after capture. Over a period of 2 years, beginning in November 1949, ovaries of 503 bigeye were collected. POFI observers with Japanese tuna mothership expeditions that operated among the Marshall and Caroline islands in the area bounded by 1° and 10°N. latitude, 145° and 179°E. longitude during the period of April to October 1951 collected ovaries from bigeye captured there. Collections from the central equatorial Pacific were made on POFI exploratory fishing expeditions, which covered an area bordered by the latitudes of 17°N. and 10°S. and the longitudes of 170°W. and 119°W. These cruises covered a period of 2 years from August 1951 to August 1953 and produced collections of ovaries for all months except April and December.

Data recorded at the time of collection included the weight or fork length of the fish, or both, and the date and location of capture. The ovaries were weighed at the laboratory after excess tissues such as the mesovarium and the attached blood vessels had been removed. The data are presented in the appendix.

Because the ovaries were obtained from longline catches as opportunity arose, the collections were deficient in several respects. The coverage of time and space was sparse, and bigeye below 30 kg. (66 lbs.) were not well represented in the longline catches.

DESCRIPTION OF OVARIES

The ovaries are paired elongate organs, circular in cross-section, lying along the dorsal wall of the body cavity. They are separate from each other except posteriorly, where the oviducts join just before entering the cloaca. In immature fish (13 kg., or 29 lbs., was the weight of the smallest examined) the ovaries are small (about 1 cm. in diameter) and firm. As the fish approach spawning condition, their ovaries become enlarged both in length and in girth. A large ripe fish may have ovaries as much as 10 cm. in diameter. The ovaries are rather flaccid when spent.

Longitudinal projections of the ovary wall incompletely partition the lumen and serve as supports for the follicular tissue. Cross-sections of immature ovaries show a plumate arrangement of the follicular tissue with the partitions as "rachises". This arrangement is obscured by large ova in maturing and mature ovaries.

DESCRIPTION OF EGGS

As in other fishes, the ovary of the bigeye contains a large reserve of small, transparent "primitive" or undeveloped eggs which periodically give rise to smaller numbers of developing eggs. The number of undeveloped eggs in a pair of ovaries, as estimated from a frequency distribution of diameters of all eggs in the ovary (fig. 1), is approximately 1 billion. The primitive eggs average 0.07 mm.[1/] and may be as large as 0.18 mm. in diameter. As these eggs develop, the deposition of yolk granules enlarges them and makes them opaque. They are fully opaque at a diameter of 0.20 mm. at which stage the weight of the ovary is about 0.004 of the weight of the fish (see page 10). Continuing deposition of yolk granules causes further enlargement of the egg, and when a diameter of 0.75 mm. is reached, oil globules begin to appear.

The beginning of translucence in larger eggs signifies the approach of ripeness. The mature eggs are translucent and spherical. Diameter frequencies of this group show modes at 0.88 mm. to 1.1 mm. Each ovum contains, in a sac, an oil globule, which appears as a yellow spot measuring 0.240 to 0.274 mm. in diameter. The oil is sometimes divided into smaller, brighter yellow spots due to the rupture of the sac. When this happens, the empty sac is usually seen with ease under magnification.

[1/] Based on formalin-preserved material.

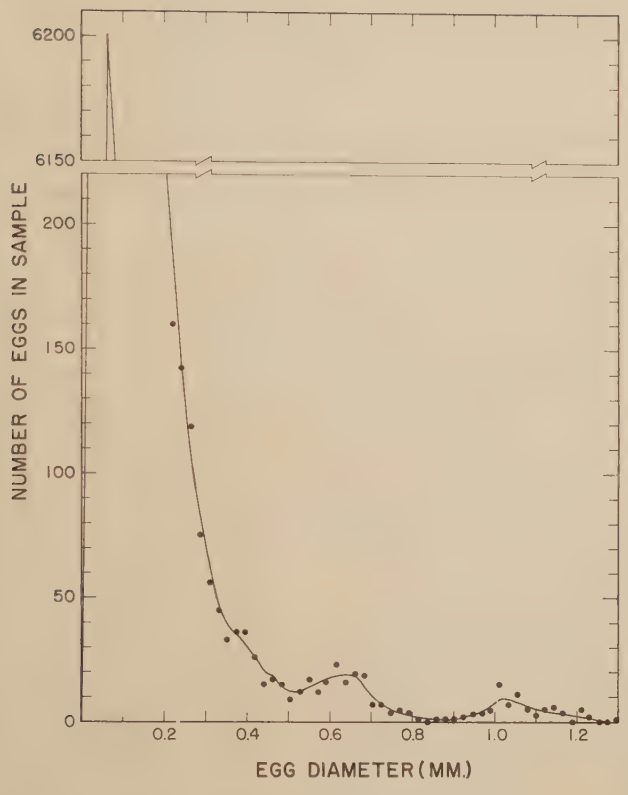

Figure 1.--Frequency distribution of egg diameters from the ripest ovary from the central equatorial Pacific (no. 57).

When the fish spawns, some mature eggs remain in the ovary and are reabsorbed. These residual eggs can be recognized by their shriveled appearance and dark coloration. In late stages of reabsorption they are often arranged in dark clumps like a string of misshapen beads imbedded in the follicular tissue.

In this paper the ovaries will be designated immature, early maturing, late maturing, and mature according to whether they are found with primitive eggs only, with opaque eggs before the appearance of oil globules, with opaque eggs with oil globules, or with large eggs which are translucent.

ESTABLISHMENT OF SAMPLING PROCEDURES

Determining the most efficient method of measuring diameters

Although basically spherical, the eggs are distorted by pressure from other eggs in the ovary. This posed a problem concerning the most efficient method of measuring an egg. One alternative was to measure the maximum and minimum diameters and average them; another was to measure the diameter which occurred, by chance, parallel to guide lines ruled in the Sedgewick-Rafter counting chamber used as a receptacle during the measuring. Both of these techniques provide estimates of the average diameter, but a greater variance would be expected with the latter that would make it less efficient. To compare the variances, 50 mature eggs were measured from an ovary (no. 24) by both procedures. The results of the measurements are recorded in units of 7.5 microns in table 1.

If the relative efficiency of the two methods is judged by their variances, 37.59 and 88.35 respectively for the averages of the maximum and minimum diameters and for the random diameters, obtaining the average diameter is 2.4 times as efficient as measuring the random diameter. In terms of work involved, however, the statistically more efficient method would require two measurements, each of which would be more time consuming than the one measurement of the random diameter. Still more work would be required to calculate the average. Measuring the random diameters was, therefore, the method selected. This diameter may be defined as the distance between two parallel lines tangent to the egg and normal to the rulings on the counting chamber.

Distribution of eggs within an ovary

The distribution of the most mature group of eggs within an ovary was studied as a further preliminary step in establishing a procedure for sampling each ovary. Cross-sections were taken from the anterior, middle, and posterior parts of the right member of the largest and seemingly most mature pair of ovaries in the collection at that time (no. 63). The sections were labelled 1, 2, and 3 respectively. From each section six samples, two near the periphery (labelled A_1 and A_2), two near the center (labelled C_1 and C_2), and two from between these positions (labelled B_1 and B_2) were taken with a cork borer 8 mm. in diameter. It was not possible, however, to obtain more than one sample from the center position of the posterior

section. These samples were weighed to the nearest 0.001 gm. The eggs of the most mature group were counted and measured to the nearest 0.02 mm. The resulting measurements and weights are recorded in table 2. The measurements, coded by subtracting 60 and multiplying by 100, were treated with an analysis of variance test (table 3). Because of the lack of one sample, the analysis of variance for data based on a single classification with unequal subsample numbers (Snedecor 1946:240-241) was used. This test showed a significant difference ($P < 0.05$) in the diameter means between positions (A, B, and C) but none between sections. The means for positions A, B, and C were 0.9606 mm., 0.9640 mm., and 0.9447 mm. respectively.

Table 1.--Maximum, minimum, and random egg diameter measurements for a single ovary (no. 24) (in micrometer units of 7.5μ)

Chance diameter	Maximum diameter	Minimum diameter	$\bar{x}$	Chance diameter	Maximum diameter	Minimum diameter	$\bar{x}$
130	161	130	145.5	144	146	116	131.0
139	139	127	133.0	132	133	110	121.5
122	142	120	131.0	140	166	128	147.0
141	152	137	144.5	138	144	135	139.5
139	143	133	138.0	129	135	124	129.5
134	138	123	130.5	135	135	124	129.5
131	132	131	131.5	150	154	119	136.5
126	142	121	131.5	132	144	128	136.0
139	139	125	132.0	134	152	129	140.5
127	130	121	125.5	143	152	124	138.0
130	140	120	130.0	136	145	127	136.0
124	155	116	135.5	110	149	109	129.0
144	144	115	129.5	132	141	129	135.0
141	145	124	134.5	126	126	123	124.5
156	156	135	145.5	142	144	134	139.0
153	153	129	141.0	107	142	106	124.0
142	143	135	139.0	143	162	127	144.5
127	155	121	138.0	138	147	132	139.5
129	140	129	134.5	128	135	124	129.5
136	146	124	135.0	121	155	121	138.0
128	149	110	129.5	144	144	127	135.5
133	135	125	130.0	127	159	109	134.0
131	138	127	132.5	131	152	131	141.5
126	129	111	120.0	134	137	129	133.0
143	153	118	135.5	125	154	125	139.5

The number of mature eggs to be expected from 0.5 grams of each sample was calculated and an analysis of variance was applied to these numbers to examine differences in the number of mature eggs per unit weight between sections and between positions. The test (table 4) showed that the mature eggs were evenly distributed throughout the ovary.

In view of these results it was decided that sampling should be done in such a manner that the eggs would be randomly picked from a cross-section of the ovary. The sampling procedure described in a later section was therefore adopted.

After the study was nearly complete, however, it was noticed that the eggs near the periphery of the ovary were always easier to tease apart than those towards the center because of a less compact arrangement of eggs in this region. This caused the homogeneity of the diameter variances between positions to be questioned, as the measuring technique used would cause the greater irregularity of egg shapes resulting from greater compactness to increase the variance in the center. In a test of homogeneity (Snedecor 1946, p. 249) the variance of 0.0035 for position A was found to differ significantly from those of positions B and C, which were

Table 2.--Weights and egg diameter frequencies of samples from the various parts of an ovary (no. 63)

Diameter (mm.)	Sample number and sample weight (gm.)																
	$1A_1$	$1A_2$	$1B_1$	$1B_2$	$1C_1$	$1C_2$	$2A_1$	$2A_2$	$2B_1$	$2B_2$	$2C_1$	$2C_2$	$3A_1$	$3A_2$	$3B_1$	$3B_2$	$3C_1$
	0.0804	0.1038	0.1037	0.1034	0.1323	0.0896	0.0862	0.1203	0.1113	0.0981	0.0923	0.1189	0.1313	0.1363	0.1222	0.1330	0.0807
0.68	-	-	-	1	-	-	-	-	-	-	2	-	-	-	-	-	-
0.70	-	-	-	0	-	-	-	-	1	-	0	2	-	-	-	-	-
0.72	-	-	1	1	2	-	-	-	1	1	1	0	-	-	-	-	-
0.74	-	-	0	0	2	-	-	-	3	0	4	1	-	1	1	-	2
0.76	-	-	4	1	4	-	-	-	2	0	2	3	-	0	1	1	0
0.78	-	-	2	0	3	2	-	-	1	3	0	2	-	1	0	1	1
0.80	-	1	4	0	0	1	1	-	4	2	4	4	1	0	5	0	1
0.82	1	0	6	3	8	2	2	6	7	3	9	7	1	1	3	3	4
0.84	0	0	3	2	4	3	2	5	6	5	9	14	4	3	9	3	2
0.86	3	1	8	4	12	9	4	10	8	5	8	14	10	3	10	2	1
0.88	5	6	3	4	11	7	10	9	8	7	11	12	5	8	20	6	5
0.90	6	3	12	10	13	6	5	17	7	12	9	10	19	16	17	9	10
0.92	10	14	14	18	16	11	9	21	9	14	9	13	21	18	13	16	12
0.94	9	15	13	12	10	10	18	25	10	15	10	19	25	25	16	19	9
0.96	13	21	6	19	14	12	20	20	6	11	7	13	28	33	15	14	7
0.98	13	15	8	18	24	11	17	20	14	14	14	11	29	20	7	23	9
1.00	14	18	13	7	18	8	18	16	12	16	14	8	16	17	9	21	11
1.02	13	12	16	8	7	8	13	12	9	7	5	11	9	15	15	12	5
1.04	8	8	3	5	12	6	4	2	4	6	5	7	8	18	8	14	6
1.06	7	2	7	6	12	3	4	2	10	9	5	3	5	6	8	10	7
1.08	5	1	5	5	6	4	2	3	5	3	2	5	3	1	3	6	4
1.10	4	0	3	1	4	1	-	2	4	4	1	2	1	3	3	3	1
1.12	2	1	1	0	6	1	-	-	2	2	1	1	1	-	2	0	0
1.14	0	-	2	3	7	-	-	-	3	1	-	1	-	-	1	2	3
1.16	1	-	2	2	2	-	-	-	2	0	-	1	-	-	-	1	1
1.18	-	-	-	-	1	-	-	-	0	1	-	0	-	-	-	-	1
1.20	-	-	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-
Sum	114	118	136	130	198	105	129	170	140	141	132	165	186	189	166	166	102

0.0073 and 0.0083 respectively. Comparisons of the variances of the different sections showed that these also were not alike. The variance of 0.0048 for section 3 was significantly smaller than the variances of 0.0066 and 0.0070 for sections 1 and 2 respectively.

Table 3.--Analysis of variance of diameters of mature eggs from different parts of the ovary

Source	Degrees of freedom	Sum of squares	Mean square
Between sections	2	2727.861	1363.931
Positions of the same section	6	2910.770	485.128*
Samples of the same position	8	666.086	83.261
Individuals of the same sample	2470	150010.449	60.733
Total	2486	156315.166	

Table 4.--Analysis of variance of numbers of mature eggs from different parts of the ovary

Source	Degrees of freedom	Sum of squares	Mean square
Between sections	2	8527.084	4263.542
Positions of the same section	6	7842.203	1307.034
Samples of the same position	8	30176.967	3772.121
Total	16	46546.254	

The diameter means of the positions and the sections were therefore recompared by a test that adjusted for the heterogeneity of variances (Cochran and Cox 1950). Not only was a difference found in the means between positions but between sections as well. The mean of position C, when compared with those of A and B, produced "t" values of 4.004 and 4.641, which are beyond the 0.001 probability level. Significant "t" values of 6.616 and 6.389 resulted when the mean of section 2 (0.9433) was tested against those of sections 1 and 3 (0.9626 and 0.9672 respectively). These results indicate shortcomings in the sampling technique used, but since the precaution had been taken to obtain all samples from the middle section (see page 7), the diameter measurements from the different ovaries are comparable.

Distribution of eggs in right and left ovaries

Another preliminary step in the investgiation was to examine possible differences between the size distributions of the eggs in the right and left members of a pair of ovaries. Samples were taken from both ovaries of a pair (no. 21) according to the sampling procedure described below. Measurements were made of all eggs with diameters greater than 0.143 mm. and recorded in table 5. This lower limit was arbitrarily picked to avoid measuring the tremendous number of smaller eggs. The frequency distributions for the right and left ovaries were compared by a chi-square test (Snedecor 1946, pp. 205-207). The result, a chi-square of 24.411 (P = 0.6, 27 d.f.[2/]), leads to the conclusion that differences between the frequency distributions of egg diameters for the right and left ovaries of the same pair are negligible.

[2/] The last three classes were combined because of their low frequencies.

Table 5.--Frequencies of egg diameters of right and left ovaries from the same fish

Class midpoint		Frequency	
(micrometer units*)	(mm.)	Right ovary	Left ovary
7	0.154	341	393
8	0.176	256	233
9	0.198	203	214
10	0.220	158	170
11	0.242	124	114
12	0.264	105	95
13	0.286	99	96
14	0.308	85	83
15	0.330	65	73
16	0.352	69	62
17	0.374	76	69
18	0.396	70	76
19	0.418	75	95
20	0.440	84	68
21	0.462	32	49
22	0.484	23	22
23	0.506	5	12
24	0.528	3	2
25	0.550	3	3
26	0.572	6	5
27	0.594	15	7
28	0.616	30	20
29	0.638	20	26
30	0.660	16	23
31	0.682	11	9
32	0.704	3	7
33	0.726	4	4
34	0.748	5	4
35	0.770	0	0
36	0.792	0	2
Sum		1986	2036

* 1 micrometer unit = 0.022 mm.

Description of sampling procedure

The following procedure was used in sampling the ovaries for egg diameter measurements. It should be pointed out that the difference of means anterio-posteriorly was not inspected when this procedure was chosen. (1) A cross section about 1/4 inch thick was taken from an ovary (always from the middle and from the left ovary, whenever possible, for the sake of uniformity). (2) The ovary wall and the projections of this wall into the lumen were removed. (3) The section was placed in an 8-ounce jar about two-thirds full of 10-percent formalin and shaken in an agitator. (4) The contents of the jar were then stirred with a metal tube which had an inner diameter of 12 mm. An erratic motion was used so that the eggs would not move in circular stream. (5) The tube was then quickly lifted out of the jar and vertically plunged back. (6) The top of the tube was closed tightly with the thumb, and tube and contents were withdrawn. (7) Steps 4 through 6 were repeated several times. (8) The samples thus obtained were combined and broken down further by teasing. (9) A subsample was taken by means of a medicine dropper with an opening of 2.5 mm. at the mouth. (10) The eggs in this subsample were measured to the nearest 0.022 mm. under a dissecting microscope.

MODES IN THE FREQUENCY DISTRIBUTION OF EGG DIAMETERS

To investigate the complete frequency distribution of egg sizes in the ovary, all the eggs in a sample from the ripest-appearing ovary from the central equatorial Pacific (no. 57) were measured. The measurements included the follicular cells, as no sharp line of demarcation exists between these and small ova. To augment the portion of the frequency distribution representing the larger eggs, a second, larger sample was taken and only eggs with diameters greater than 0.165 mm. were measured. Samples 1 and 2 (table 6) were combined and smoothed twice by a moving average of three to produce the frequency distribution shown in figure 1. In combining the samples an adjustment of sample 2 had to be made to account for eggs smaller than 0.165 mm. which had not been counted. The number of eggs in sample 2 was about 1.5 times the number of eggs over 0.165 mm. in sample 1. It was assumed large and small eggs were present in the same proportion in both samples. Hence the smaller classes of sample 2 were estimated as 1.5 times the same classes of sample 1. Besides the prominent mode resulting from the tremendous number of primitive eggs, two modes of maturing eggs (and possibly a third at 0.38 mm.) are evident.

Table 6.--Frequencies of egg diameters of most mature ovaries from Hawaiian area, western equatorial Pacific, and central equatorial Pacific

Class midpoint		Central Pacific		Western Pacific	Hawaiian area
(micrometer units)	(mm.)	Sample 1	Sample 2		
1	0.022	228	-	-	-
2	0.044	1598	-	-	-
3	0.066	2481	-	-	-
4	0.088	2249	-	-	-
5	0.110	1698	-	-	-
6	0.132	816	-	255	217
7	0.154	363	-	148	168
8	0.176	166	193	88	91
9	0.198	119	110	65	51
10	0.220	71	89	42	18
11	0.242	60	82	39	20
12	0.264	42	77	29	23
13	0.286	31	44	26	21
14	0.308	18	38	34	14
15	0.330	10	35	27	8
16	0.352	8	25	26	14
17	0.374	14	22	35	9
18	0.396	11	25	23	8
19	0.418	11	15	13	14
20	0.440	6	9	23	7
21	0.462	4	13	13	9
22	0.484	5	10	21	6
23	0.506	3	6	20	10
24	0.528	3	9	22	3
25	0.550	5	12	16	6
26	0.572	1	11	10	6
27	0.594	2	14	11	8
28	0.616	5	18	4	6
29	0.638	3	13	1	8
30	0.660	3	16	0	15

Table 6.--Frequencies of egg diameters of most mature ovaries from Hawaiian area, western equatorial Pacific, and central equatorial Pacific - Continued

Class midpoint		Central Pacific		Western Pacific	Hawaiian area
(micrometer units)	(mm.)	Sample 1	Sample 2		
31	0.682	7	11	0	6
32	0.704	2	5	0	8
33	0.726	3	4	1	4
34	0.748	0	4	1	2
35	0.770	0	5	0	4
36	0.792	1	3	3	1
37	0.814	1	0	5	-
38	0.836	0	0	9	-
39	0.858	0	1	7	-
40	0.880	0	1	6	-
41	0.902	0	1	10	-
42	0.924	0	2	6	-
43	0.946	0	3	14	-
44	0.968	2	1	13	-
45	0.990	3	1	9	-
46	1.012	4	11	7	-
47	1.034	3	4	6	-
48	1.056	1	10	2	-
49	1.078	1	4	0	-
50	1.100	1	2	1	-
51	1.122	0	5	0	-
52	1.144	1	5	1	-
53	1.166	-	4	1	-
54	1.188	-	0	-	-
55	1.210	-	5	-	-
56	1.232	-	2	-	-
57	1.254	-	0	-	-
58	1.276	-	0	-	-
59	1.298	-	1	-	-
Sum		10064	981	1093	785

For comparative purposes the ripest-appearing ovaries from the Hawaiian area (no. B472) and the western equatorial Pacific (no. 1002) were also selected for detailed study. The numerous eggs smaller than 0.121 mm. were excluded, however, since ovary no. 57 had already provided information about this part of the frequency distribution. The smoothed frequency distribution of egg diameters of the ovary from the western equatorial Pacific (fig. 2) shows three definite groups of maturing eggs at 0.35 mm., 0.51 mm., and 0.98 mm. The ovary from the Hawaiian area (fig. 2) shows a definite last mode at 0.66 mm., which is a position below those of the last modes of the ovaries of the other two areas. Two more modes of maturing eggs are suggested at 0.29 mm. and 0.40 mm. The fact that these two suspected modes are at positions slightly to the left of comparable but better defined modes in more mature ovaries strengthens the possibility that they are real.

RELATION OF RELATIVE OVARY WEIGHT TO DEGREE OF RIPENESS

In order to determine more accurately the position of the final mode in the size frequency distribution of eggs for all ovaries, systematic measuring of ova representing that mode was begun. Whenever the group of largest eggs was not distinguishable from the rest of the eggs by its physical characteristics, measuring was started with eggs which were considered small

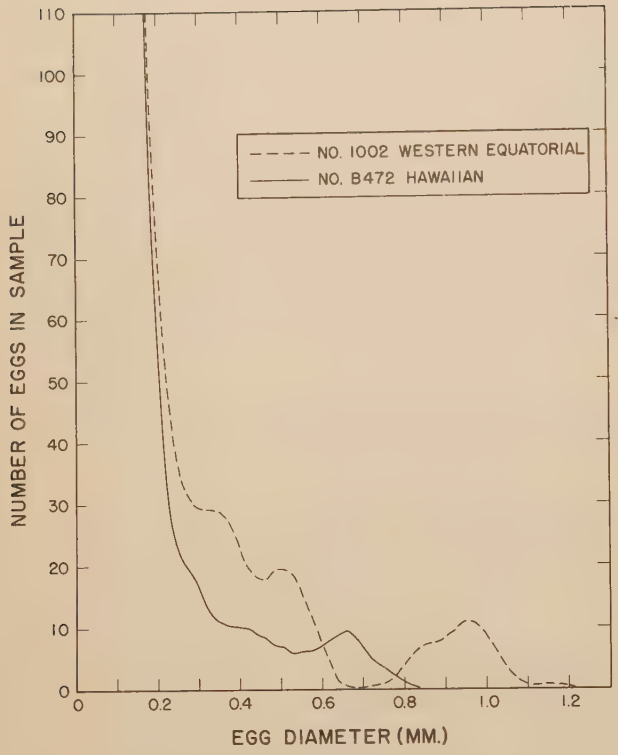

Figure 2.--Egg diameter frequencies from ripest ovaries of Hawaiian and western equatorial Pacific areas.

enough to be definitely outside the lower limits of the group. The resulting frequency distribution was then smoothed twice by a moving average of three and plotted. The descending slope of the second to the last group of eggs of this plot was then extended by eye. The amount under this extension at each size class was subtracted from the total at that size to get the ascending slope of the most mature group and its mode. This is illustrated in figure 3. By experimentally shifting the extension to the right and left to its apparent limits, the mode was shifted 0.04 mm. at the very most. If the shift was too much to the left, the frequency distribution of the largest group of eggs would become bimodal. Overshifting to the right had very little effect in the position of the mode.

After 33 ovaries from the central equatorial Pacific had thus been investigated, a relation between modal position and relative ovary weight (ovary weight/fish weight) was sought. The diameter frequencies of the samples from these ovaries are listed in table 7 with asterisks (*) marking the modal positions. As shown in figure 4, the relation between modal diameter and relative ovary weight appears to be curvilinear. To determine the best mathematical relation, three regression lines were fitted to the data. The modal diameter[3/] and the relative ovary weight x 103[4/] were used as the variates for one line; modal diameter and the logarithm of the relative ovary weight were variates for another; and logarithms for both modal diameter and relative ovary weight were variates for the third line. The sums of squares of deviation from these lines were 3396.91, 788.35, and 878.85 respectively. The line of best fit, the semi-logarithmic relation, may be described by the equation:

$$\hat{Y} = 0.7055\ X - 0.1478$$

where $\hat{Y}$ is the modal diameter in millimeters and X is the log (relative ovary weight). The regression coefficient ($b = 0.7055$) differs significantly from 0 ($t = 9.965$, $P < 0.001$). The correlation coefficient ($r = 0.88$) is also highly significant ($P < 0.01$).

Positions of the last mode for six ovaries from the western equatorial area were examined to determine if the same relation held for the two areas. The six ovaries were selected to cover the range of logarithms of relative ovary weights. The frequency distributions are tabulated in table 8. The regression of modal diameter on log (relative ovary weight) was calculated, yielding the equation:

$$\hat{Y} = 0.6178\ X - 0.0597$$

The symbolism is the same as that in the previous paragraph.

[3/] Coded by using micrometer units. One micrometer unit = 0.022 mm.

[4/] Called hereafter simply "relative ovary weight".

Table 7.--Frequencies of egg diameters for ovaries from the central equatorial Pacific showing position of mode of most mature group

| Ovary number | Class midpoint | | |

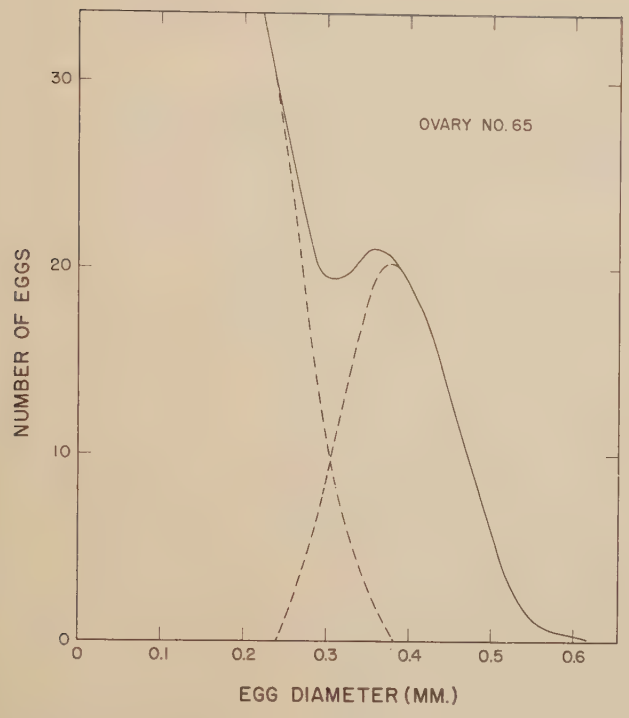

Figure 3.--Method of determining position of mode.

The data for the two regions were compared by the analysis of covariance (Snedecor 1946, pp. 318-321). The results (table 9) showed that the differences between them were so small that the data could be considered together. Combining the data from both regions resulted in the following equation of regression:

$$\hat{Y} = 0.6935\,X - 0.1367$$

In order to determine at what level of relative ovary weight the eggs first show signs of maturing, i. e. begin to turn opaque, all central and western equatorial Pacific ovaries with relative ovary weights smaller than 7 were sampled and investigated for opaque eggs. Randomly picked ovaries from the first year of collection in the Hawaiian area were also investigated. These are noted in the tables in the appendix. The few ovaries with a relative ovary weight of 2 were all immature. Only 11 percent of the ovaries with a relative ovary weight of 3 had eggs in the early maturing stage, whereas 65 percent of those with a relative ovary weight of 4 had such eggs.

The possibility of using the relative ovary weight as a tool for measuring the ripeness of a fish easily and objectively now arises. The size of the egg at the different stages of ripeness is known (page 2). This size may be predicted from the relative ovary weight. Thus, by using the regression of modal diameter on relative ovary size, relative ovary weight values were assigned to the different classes of ripeness as follows: 0 to 3 are considered immature, 4 to 18 early maturing, 19 to 28 late maturing, and larger than 28 mature. Spent fish are not recognized by this method, being classified in the stage of maturity which represents the most advanced of the remaining groups of eggs.

A certain amount of error is involved in classifying the degree of ripeness using relative ovary weights. This error was estimated by: (1) calculating the probabilities of sampling a fish in the immature stage and classifying it as immature, early maturing, late maturing, and mature; of sampling a fish in the early maturing stage and classifying it as immature, early maturing, late maturing, and mature; etc. (Pearson 1931, tables VIII and IX); (2) calculating a percentage of error for each category based on these probabilities (see below). The probabilities (table 10) are based on a theoretical population of which the 33 ovaries used for the regression line for the central equatorial Pacific (page 10) constitute a sample. The ovaries involved in the regression computations of the western equatorial Pacific were not used as these had been selected not randomly but according to their relative ovary weights.

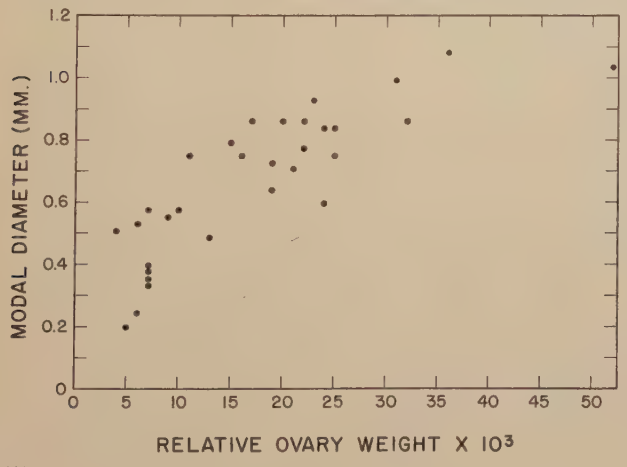

Figure 4.--Relation of modal diameter to relative ovary weight.

If the probability of an individual fish actually being in the stage of ripeness in

Table 8.--Frequencies of egg diameters for ovaries from the western equatorial Pacific showing position of mode of most mature group

Class midpoint		Ovary number					
(micrometer units)	(mm.)	1019	1029	1039	1065	1081	1092
10	0.220	-	-	-	37	43	-
11	0.242	-	-	-	32	42	-
12	0.264	-	-	-	42	34	-
13	0.286	-	-	-	30	34	-
14	0.308	-	-	36	24	20	-
15	0.330	-	23	30	16	21	-
16	0.352	-	27	27	21	22	-
17	0.374	-	25	15	13	17	-
18	0.396	-	30	10	10	16	-
19	0.418	-	23	17	13	15	-
20	0.440	-	23	20	9	14	-
21	0.462	-	25	12	6	12	-
22	0.484	-	23	11	7	12	-
23	0.506	-	27	13	18*	15	-
24	0.528	-	22	21	9	13	-
25	0.550	-	25	13	10	16	-
26	0.572	-	21	24*	4	18*	-
27	0.594	-	11	17	13	11	-
28	0.616	-	12	15	5	6	-
29	0.638	-	17	18	5	7	-
30	0.660	-	16	8	7	2	-
31	0.682	-	20	5	5	1	-
32	0.704	2	13*	2	1	-	1
33	0.726	0	13	2	1	-	2
34	0.748	1	9	2	-	-	5
35	0.770	1	7	1	-	-	7
36	0.792	3	4	1	-	-	16
37	0.814	6	1	-	-	-	18
38	0.836	11	1	-	-	-	24
39	0.858	18	-	-	-	-	23*
40	0.880	13	-	-	-	-	24
41	0.902	20	-	-	-	-	25
42	0.924	16	-	-	-	-	15
43	0.946	16	-	-	-	-	7
44	0.968	26*	-	-	-	-	8
45	0.990	18	-	-	-	-	3
46	1.012	14	-	-	-	-	2
47	1.034	12	-	-	-	-	1
48	1.056	9	-	-	-	-	-
49	1.078	2	-	-	-	-	-
50	1.100	0	-	-	-	-	-
51	1.122	2	-	-	-	-	-
52	1.144	1	-	-	-	-	-
Sum		191	418	320	338	391	181

* Position of mode

Table 9.--Analysis of covariance of largest modal diameter on relative ovary weight regressions for the western and central equatorial Pacific

Source	Degrees of freedom	Errors of estimate	
		Sum of squares	Mean squares
Between regions	1	3.195	3.195[1/]
Within regions	35	879.430	25.127
Total	36	882.625	

[1/] This unusually low figure is suspect, but recomputation has shown it to be correct.

Table 10.--Probabilities of ovaries occurring in various stages of maturity using two methods of classification

Classification by modal diameters	Classification by relative ovary weights				
	Immature	Early maturing	Late maturing	Mature	Sums
Immature	.009	.008	.000	.000	.017
Early maturing	.006	.547	.060	.016	.629
Late maturing	.000	.057	.074	.025	.156
Mature	.000	.015	.061	.122	.198
Sums	.015	.627	.195	.163	1.000

which it is placed is considered, this method of classification results in considerable error, especially in stages where the range of egg sizes is small, such as the late maturing stage. Only 38 percent of the fish classified as late maturing would actually be in the late maturing stage. In the early maturing stage, however, which has a large range of egg sizes, 87 percent of the fish would be correctly classified.

This error in classifying individual fish does not invalidate the method for use in group statistics, as the number of fish lost to one stage due to misclassification is somewhat balanced by the number of fish gained by that stage due to misclassification in the opposite direction; e.g., the number of immature fish classified as early maturing is somewhat balanced by the number of early maturing fish classified as immature. The calculated percentage of error mentioned earlier represents the error in the number placed in each group. The expected number in a group resulting from classification by relative ovary weights is either lower or higher than the expected number actually in the group. The amounts and the direction of error are 11.8 percent too low for the immature group, 0.3 percent too low for the early maturing group, 25.0 percent too high for the late maturing group, and 17.7 percent too low for the mature group. An example of the way these percentages were arrived at follows: the probabilities of classifying a fish in the immature stage according to relative ovary weights are 15 in a thousand (sum of column labelled immature, table 10); the probabilities of a fish actually being immature are 17 in a thousand (sum of row labelled immature); the error is 2/17 or 11.8 percent.

Since the amount of material was too small for quantitative procedures in those aspects of the study which consider the stage of ripeness, the use of relative ovary weights as a measure of ripeness was thought to be justified.

SIZE AT FIRST SPAWNING

If fish sizes are plotted against stages of maturity, the size at first spawning should become evident. Although fish larger than the size at first spawning could be in any stage of maturity, those below this size would all be immature. A plot of this type was made (fig. 5) using fish weight and relative ovary weight as measures of size and maturity respectively.

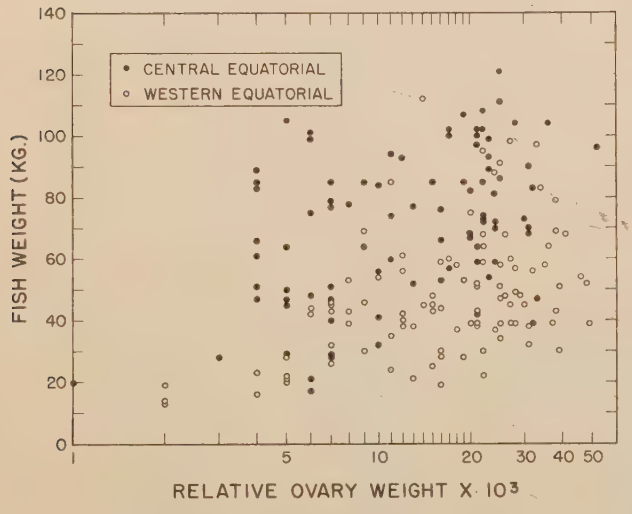

Figure 5.--Plot of fish weight against relative ovary weight.

In this plot the maturing fish (those having relative ovary weights of 4 or greater) were almost all over 20 kg. (44 lbs.) while four of the five immature fish (those having relative ovary weights of 3 or less) weighed less. The number of fish below 20 kg., is insufficient to set more definitely the size at first spawning.

Data from the equatorial Pacific and the Hawaiian area are contradictory as to what happens in the ovaries after spawning. Figure 5 indicates that once a fish spawns its ovaries never revert to the immature stage of having only primitive eggs. This is shown by the fact that, with one exception, none of the relative ovary weights of fish greater than 20 kg. were less than 4. Many fish weighing as much as 100 kg. (220 lbs.) from Hawaiian waters were immature according to their relative ovary weights.

Since there were relatively few fish of 20 kg. and under, the ovaries of these fish were subjected to further study in an effort to find indications of past spawning, such as residual eggs. Although the absence of these eggs would not necessarily mean that spawning had not taken place, as they might have been completely reabsorbed, their presence would mean that spawning had occurred. Five of the seven ovaries examined did not have residual eggs. Only two fish of 14 and 17 kg. (31 and 37 lbs.) did have residual eggs. The size at first spawning, therefore, ranges from 14 kilograms (possibly less) to 20 kilograms. This agrees with Kikawa (1953), who stated that the size at first spawning is roughly 90 to 100 cm. This corresponds to fish of 16 to 21 kg. (see table B, footnote 3).

Moore (1951), working on the age and growth of the yellowfin in the Hawaiian fishery, estimated that the yellowfin grows from a weight of 7 to a weight of 46 pounds (3 to 20 kg.) in its second year of growth. If the bigeye, which weighs slightly more than yellowfin of comparable lengths and attains a greater size, can be assumed to have a growth rate of this magnitude in its early years, the range of size variation within a year class could include individuals of 14 and 20 kg. Only a greater sampling of fish in the lower size range and a study of age and growth, however, will definitely answer the question of age of sexual maturity.

TEMPORAL AND SPATIAL DISTRIBUTION OF RIPE OVARIES

Positions of capture of bigeye in the late maturing and mature stages (fig. 6) show that these fish are widely scattered in the equatorial regions. Kikawa (1953) who worked in the western equatorial Pacific also found this to be true but with an apparent concentration in the Keats Bank area ($5^{\circ}53.8'$N., $173^{\circ}29.4'$E.).

Although ovaries in the late maturing and mature stages were obtained 400 miles to the southeast of Hawaii at 14°N., 150°W., they were completely absent among the 503 of the Hawaiian collection.

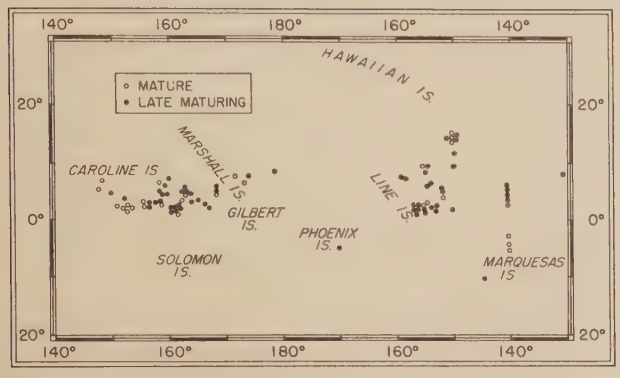

Figure 6.--Locations of capture of bigeye in late maturing and mature stages.

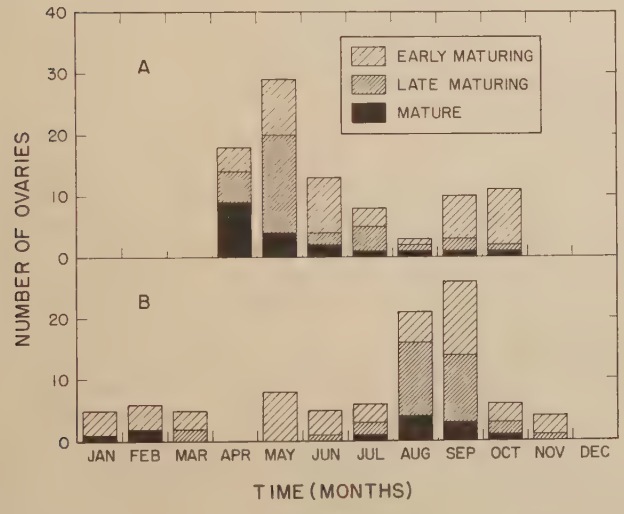

Figure 7.--Plot of numbers of bigeye at various stages of maturity against time.
A - bigeye from the western Pacific;
B - bigeye from the central Pacific.

The numbers of fish in the different stages of maturity are shown for each month for each equatorial area (fig. 7). The separation into stages was done according to the relative ovary weights. All fish under 20 kg. or with relative ovary weights of less than 4 were judged to be sexually immature and were omitted.

Mature fish were found throughout the period of collection, April through October, in the western equatorial Pacific (fig. 7A). This lengthens the known period of occurrence of mature fish in this area. Shimada (1951) and Kikawa (1953) had previously found mature bigeye from June to September and June to August, the periods to which their collections were limited.

The data from the central equatorial Pacific suggest two separate spawning periods, one in January and February and the other from July to October (fig. 7B). This cannot be accepted as a firm conclusion, however, because of the small number of samples per month and the lack of data in April, the month of apparently greatest spawning activity in the western equatorial area.

Data from the Hawaiian area show a more definite but somewhat different picture. Relative ovary weight frequencies for each month (fig. 8) reveal an increase of relative ovary weights from winter to summer. The monthly mean modal diameters (table 11) calculated from the equation $\hat{Y} = 0.6935 X - 0.1367$ (see page 13) show a definite seasonal increase when plotted against time (fig. 9). The mean diameter at the peak month of June, however, is far below that expected of a spawning population. It is interesting to note here that the commercial catch of bigeye in Hawaii is at its annual minimum during the summer (Otsu 1954). The cessation of mean modal diameter increase in June coupled with the low summer catches suggests that maturing bigeye in Hawaiian waters leave before they are mature. The possibility of their being present but not biting can be ruled out by the fact that they do bite on the same type of gear in equatorial waters.

TYPE OF SPAWNING

If one looks at the frequency distributions of egg diameters of the entire ovary (figs. 1 and 2), several modes of maturing eggs are seen. These modes could represent either groups of eggs that will be spawned in one season or groups of eggs that will be spawned in succeeding seasons, depending upon the rate of growth of the egg. It was intended at first to find the growth rate of the maturing egg and thus find out whether the modes of the smaller maturing eggs could advance to the position of the mature eggs within the length of the spawning season. This plan had to be abandoned when it proved impossible to define the spawning season with the available data.

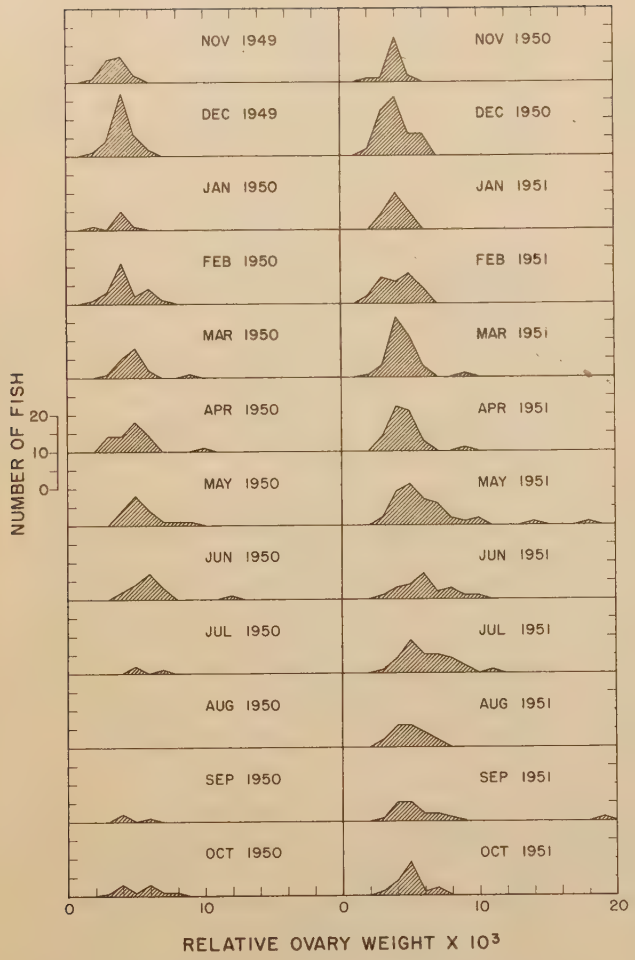

Figure 8.--Monthly frequency of relative ovary weights for bigeye collected in Hawaiian waters.

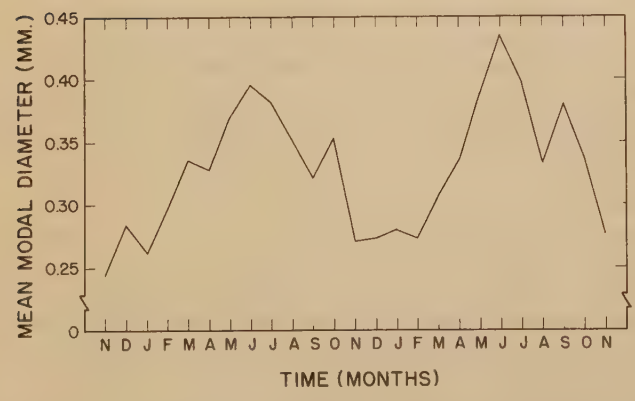

Figure 9.--Plot of mean modal diameter against time for bigeye of Hawaiian waters.

From observations on residual eggs, fractional spawning is strongly suspected. The frequency of occurrence of randomly selected ovaries with no residual eggs, with residual eggs in the early stages of reabsorption (characterized by the presence of an oil globule, the still tough outer membrane, and translucence), or with residual eggs in the late stages of reabsorption (eggs which were opaque, small, and dark) was observed. Of the 121 ovaries examined, 60 had no residual eggs, 13 had eggs in the early stages of reabsorption, and 48 had eggs in the late stages of reabsorption. The small number of ovaries with eggs in the early stages (10.7 percent) indicates that residual eggs are not long in this stage; yet four ovaries had residual eggs in early stages of reabsorption together with developing eggs in the late maturing or mature stages. This fact indicates a possibility of at least two spawnings in close succession.

FECUNDITY

In selecting the ovaries for this study, the fish were arranged in the following weight classes: below 100 lb. (45.4 kg.), 100 lb. to 129 lb. (45.4 kg. to 58.7 kg.), 130 lb. to 159 lb. (58.7 kg. to 72.3 kg.), 160 lb. to 189 lb. (72.3 kg. to 86.0 kg.), 190 lb. to 219 lb. (86.0 kg. to 99.6 kg.), and over 220 lb. The ovaries from each class were then inspected and only those with maturing eggs easily distinguished from the smaller eggs were considered. From this group of ovaries an attempt was made to select at random two ovaries from each size class. In the two smallest groups, only one suitable ovary for each class was found.

Pie-sections were cut from transverse slices from the middle portion of the ovary and weighed immediately to the nearest .001 gram. The number in the most mature group of eggs in the section was then determined by actual count and multiplied by the ovary weight/sample weight to get an estimate of the number of maturing or maturing eggs in the ovary.

Estimates of the number of eggs per spawning (table 12) range from 2.9 million to 6.3 million. A plot of fecundity against fish weight (fig. 10) shows that larger fish tend to have more eggs per spawning with wide variations between fish of the same size. The relation between number of eggs spawned and fish weight appears to be curvilinear.

Table 11.--Monthly mean modal diameters for the Hawaiian area

Year	Month	Mean modal diameter (mm.)
1949	November	0.2437
	December	0.2839
1950	January	0.2620
	February	0.2966
	March	0.3361
	April	0.3281
	May	0.3693
	June	0.3961
	July	0.3818
	August	--
	September	0.3215
	October	0.3532
	November	0.2707
	December	0.2732
1951	January	0.2803
	February	0.2734
	March	0.3060
	April	0.3357
	May	0.3874
	June	0.4349
	July	0.3973
	August	0.3336
	September	0.3800
	October	0.3383
	November	0.2759

Table 12.--Data for estimations of the number of mature eggs in ovaries

Ovary number	Fish weight (kg.)	Ovary weight (gm.)	Sample weight (gm.)	Number of mature eggs in sample	Estimated number of mature eggs in pair of ovaries (millions)
2	76	1229	0.761	2429	3.9
3	102	2130	2.301	6842	6.3
8	91	2217	1.969	3943	4.4
12	107	2048	1.527	3086	4.1
30	57	970	0.763	2409	2.9
31	72	1597	0.905	1863	3.3
48	85	993	1.579	6240	3.9
51	90	2818	2.456	2977	3.4
60	39	1268	1.353	3095	2.9
63	65	2351	2.677	3310	2.9

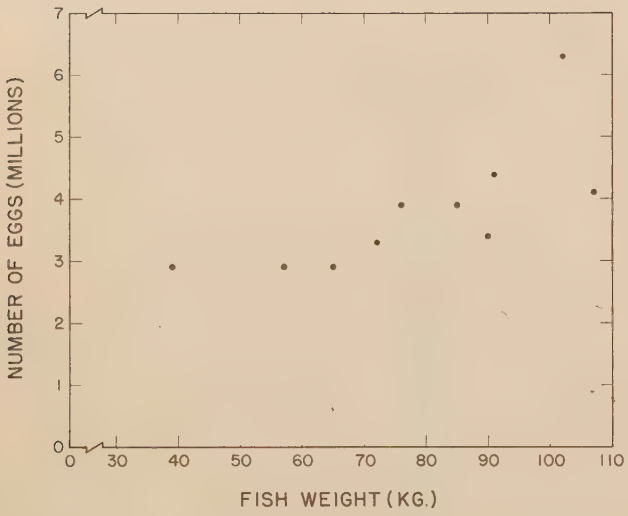

Figure 10.--Relation of number of eggs spawned to fish size.

SUMMARY

This study is based on examinations of the ovaries and the eggs within the ovaries of the bigeye tuna, Parathunnus sibi. Material collected from the western equatorial and central Pacific Ocean was used.

Investigations were made of egg diameter distributions in the ovaries to determine sampling procedures and the following findings resulted: (1) In a pair of ovaries the distribution of egg diameters in the right member is the same as the distribution in the left member; (2) eggs of the most mature group in an ovary are evenly distributed throughout the ovary; and (3) the variance of diameters of mature eggs is least at the periphery and the posterior of the ovary.

Frequency distributions of egg diameters of maturing and mature ovaries were multimodal. The most evident modes were those of the undeveloped and the most mature groups of eggs. There were suggestions of as many as two modes of maturing groups between these. The ovary weight relative to the fish weight was found to be associated with the mode of the most mature group of eggs in the ovary. The equation best describing the relation was calculated: $\hat{Y} = 0.6935 X - 0.1367$ where $\hat{Y}$ is the modal diameter in millimeters and X is the ovary weight x 10^3/fish weight.

Indications of bigeye spawning were found in the western equatorial Pacific, the central equatorial Pacific, and locations 400 miles southeast of Hawaii, but none were found in Hawaiian waters.

The extent of the spawning season could not be determined with certainty. Bigeye in advanced stages of ripeness were caught in the central equatorial Pacific in January, February, July, August, September, and October. In the western equatorial Pacific fish near spawning were taken from April through October. Evidence of more than one spawning per season was found.

The size at which the bigeye first spawns was found to be about 14 to 20 kg.

The number of eggs extruded per spawning ranges from 2.9 to 6.3 million and depends roughly on the size of the fish.

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APPENDIX

Data on Ovaries Collected

Table A.--Data on ovaries collected in Hawaiian waters

Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3	Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3
B1	88	424	11/22/49	5	B49[2/]	72	281	1/6/50	4
B2	81	313	Do.	4	B50[2/]	76	301	Do.	4
B3	87	267	Do.	3	B51	75	270	1/26/50	4
B4	91	211	Do.	2	B52[1/]	82	351	1/27/50	4
B5[2/]	70	245	Do.	4	B53[1/]	106	530	Do.	5
B6	40	125	11/23/49	3	B54	62	219	2/1/50	4
B7[1/]	98	429	11/25/49	4	B55[1/]	83	356	Do.	4
B8	62	249	Do.	4	B56	81	325	2/2/50	4
B9	60	222	Do.	4	B57	76	284	2/3/50	4
B10[2/]	57	175	11/28/49	3	B58	71	247	Do.	3
B11	54	254	Do.	5	B59	71	267	Do.	4
B12	88	368	Do.	4	B60[2/]	64	209	2/6/50	3
B13[2/]	62	208	Do.	3	B61	70	276	Do.	4
B14	64	205	Do.	3	B62	93	539	Do.	6
B15[2/]	67	230	11/30/49	3	B63	105	838	Do.	8
B16[1/]	66	242	Do.	4	B64	67	240	2/8/50	4
B17	64	230	12/5/49	4	B65[1/]	62	282	2/13/50	5
B18	102	369	Do.	4	B66	63	193	Do.	3
B19	69	287	Do.	4	B67	78	459	2/14/50	6
B20[1/]	88	563	Do.	6	B68	59	258	Do.	4
B21	66	219	12/6/49	3	B69	83	367	2/16/50	4
B22	65	356	Do.	5	B70[1/]	83	458	Do.	6
B23	69	374	12/8/49	5	B71	75	271	Do.	4
B24	100	443	Do.	4	B72	42	90	2/21/50	2
B25[2/]	87	340	Do.	4	B73	59	340	Do.	6
B26	93	535	Do.	6	B74	62	306	Do.	5
B27	60	232	Do.	4	B75[1/]	64	266	Do.	4
B28	61	182	12/9/49	3	B76	64	281	Do.	4
B29	94	369	Do.	4	B77	82	778	3/2/50	9
B30[2/]	63	242	Do.	4	B78	79	444	Do.	6
B31	75	295	12/15/49	4	B79	96	516	3/3/50	5
B32	75	409	Do.	5	B80[1/]	64	278	Do.	4
B33	77	390	Do.	5	B81	69	274	3/7/50	4
B34	72	315	12/16/49	4	B82	68	188	Do.	3
B35[1/]	96	440	12/20/49	5	B83	103	476	3/8/50	5
B36	52	192	Do.	4	B84[1/][2/]	88	445	Do.	5
B37	101	331	12/21/49	3	B85[2/]	65	295	3/16/50	5
B38	73	314	Do.	4	B86	64	342	3/21/50	5
B39	48	114	12/22/49	2	B87	56	318	Do.	6
B40[2/]	66	237	Do.	4	B88	63	288	Do.	5
B41	78	326	Do.	4	B89[1/]	93	489	3/23/50	5
B42	85	306	12/23/49	4	B90[1/]	68	302	Do.	4
B43	90	410	12/27/49	5	B91	55	207	3/30/50	4
B44	65	283	Do.	4	B92	85	398	Do.	5
B45[2/]	59	228	12/30/49	4	B93	57	204	3/31/50	4
B46	85	244	Do.	3	B94	43	111	4/4/50	3
B47	21	32	1/6/50	2	B95[1/]	93	452	Do.	5
B48[1/]	58	209	Do.	4	B96	63	247	4/5/50	4

Table A.--Data on ovaries collected in Hawaiian waters--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3	Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3
B97 [2]	87	395	4/7/50	5	B149 [1]	90	442	6/20/50	5
B98 [2]	64	169	Do.	3	B150 [1]	64	768	6/21/50	12
B99	90	288	4/10/50	3	B151 [1]	70	303	6/22/50	4
B100 [1]	100	1137	4/11/50	11	B152 [1]	92	627	7/6/50	7
B101	94	478	Do.	5	B153 [1]	74	400	7/11/50	5
B102	53	238	Do.	4	B154 [1]	88	469	7/25/50	5
B103	69	210	4/13/50	3	B155 [1]	-	-	-	-
B104 [1]	51	235	4/14/50	5	B156 [1]	46	274	9/1/50	6
B105 [1]	53	299	4/18/50	6	B157 [1]	68	259	9/15/50	4
B106	56	240	4/20/50	4	B158 [1]	94	350	9/21/50	4
B107	73	326	Do.	4	B159 [1]	100	440	10/11/50	4
B108	60	339	4/21/50	6	B160 [1]	97	759	10/20/50	8
B109 [2]	95	407	Do.	5	B161 [1]	68	407	Do.	6
B110 [2]	58	266	4/27/50	5	B162	78	324	Do.	4
B111	104	642	4/28/50	6	B163 [1]	78	496	Do.	6
B112 [1]	73	371	Do.	5	B164 [2]	106	679	Do.	6
B113 [1]	67	338	Do.	5	B165 [2]	40	111	10/26/50	3
B114 [1]	59	333	Do.	6	B166	79	344	Do.	4
B115 [1]	74	280	5/2/50	4	B167	88	626	10/28/50	7
B116	73	318	Do.	4	B168	88	453	10/31/50	5
B117	60	353	Do.	6	B169 [1]	78	314	11/10/50	4
B118	100	633	5/4/50	6	B170 [1]	83	320	Do.	4
B119 [1]	77	542	Do.	7	B171	105	-	Do.	-
B120 [1]	76	354	5/9/50	5	B172	81	396	Do.	5
B121	65	278	Do.	4	B173	60	244	11/17/50	4
B122	60	351	Do.	6	B174 [2]	79	309	11/24/50	4
B123	86	458	5/12/50	5	B175 [2]	77	326	Do.	4
B124 [1]	71	381	Do.	5	B176	48	190	11/26/50	4
B125 [1]	82	446	5/18/50	5	B177	89	395	11/28/50	4
B126 [1]	68	324	Do.	5	B178	76	313	Do.	4
B127	61	357	Do.	6	B179	77	290	Do.	4
B128	58	266	Do.	5	B180	72	283	11/29/50	4
B129 [1]	66	318	5/19/50	5	B181	58	264	Do.	5
B130 [1]	70	391	5/23/50	6	B182	112	426	Do.	4
B131	59	315	Do.	5	B183	93	359	Do.	4
B132	76	689	5/25/50	9	B184 [1]	40	74	11/30/50	2
B133	81	670	5/26/50	8	B185 [1]	87	302	Do.	3
B134 [1]	67	239	Do.	4	B186	80	392	12/1/50	5
B135 [1]	84	298	6/2/50	4	B187	70	264	Do.	4
B136	63	378	Do.	6	B188	88	470	12/4/50	5
B137	61	314	Do.	5	B189 [2]	112	720	Do.	6
B138	69	326	6/13/50	5	B190 [2]	83	362	12/5/50	4
B139 [1]	77	471	Do.	6	B191	77	413	Do.	5
B140 [1]	76	503	Do.	7	B192	99	260	12/6/50	3
B141	73	352	Do.	5	B193	76	322	Do.	4
B142	65	363	Do.	6	B194 [2]	41	97	Do.	2
B143	83	472	6/14/50	6	B195 [2]	63	215	12/7/50	3
B144 [1]	50	320	Do.	6	B196	73	253	Do.	3
B145 [1]	89	662	6/16/50	7	B197	78	280	12/8/50	4
B146	55	323	6/18/50	6	B198	74	236	Do.	3
B147 [1]	76	440	Do.	6	B199	93	520	12/11/50	6
B148 [1]	79	575	6/20/50	7	B200	79	281	Do.	4

Table A.--Data on ovaries collected in Hawaiian waters--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight $\times 10^3$	Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight $\times 10^3$
B201	47	128	12/11/50	3	B253	69	323	2/7/51	5
B202	93	403	12/12/50	4	B254	43	258	Do.	4
B203	76	260	Do.	3	B255	37	85	Do.	2
B204	71	216	Do.	3	B256	73	336	Do.	5
B205	41	236	12/13/50	3	B257	74	255	Do.	3
B206	56	211	Do.	4	B258	41	103	Do.	3
B207	93	410	12/14/50	4	B259	50	125	Do.	2
B208	90	363	Do.	4	B260	79	441	2/9/51	6
B209	38	116	12/15/50	3	B261	76	401	Do.	5
B210	44	125	Do.	3	B262	80	262	Do.	3
B211	68	386	12/18/50	6	B263	55	311	2/14/51	6
B212	73	288	Do.	4	B264	79	360	Do.	5
B213	86	395	Do.	5	B265	68	297	Do.	4
B214	91	384	Do.	4	B266	52	169	Do.	3
B215	92	395	12/20/50	4	B267	91	350	Do.	4
B216	70	324	Do.	5	B268	103	633	2/15/51	6
B217	77	470	12/22/50	6	B269	53	169	2/20/51	3
B218	82	333	Do.	4	B270	75	293	Do.	4
B219	56	217	12/26/50	4	B271	54	192	Do.	4
B220	84	368	Do.	4	B272	35	103	Do.	3
B221	100	437	Do.	4	B273	77	438	Do.	6
B222	89	526	Do.	6	B274	36	111	2/28/51	3
B223	122	714	12/27/50	6	B275	72	321	3/7/51	4
B224	38	120	12/28/50	3	B276	71	285	Do.	4
B225	45	138	Do.	3	B277	56	247	Do.	4
B226	42	102	12/29/50	2	B278	90	297	3/9/51	5
B227	71	369	Do.	5	B279	43	157	Do.	4
B228	83	349	1/24/51	4	B280	78	384	Do.	5
B229	77	387	1/25/51	5	B281	77	332	3/12/51	4
B230	64	235	Do.	4	B282	37	88	Do.	2
B231	95	490	Do.	5	B283	41	110	3/13/51	3
B232	86	337	1/26/51	4	B284	68	36	Do.	5
B233	50	129	Do.	3	B285	88	396	3/14/51	4
B234	50	162	1/29/51	3	B286	80	349	Do.	4
B235	54	186	Do.	3	B287	51	208	3/15/51	4
B236	60	256	Do.	4	B288	69	331	Do.	5
B237	76	305	Do.	4	B289	78	363	Do.	5
B238	78	332	1/30/51	4	B290	71	289	3/19/51	4
B239	64	253	Do.	4	B291	92	805	Do.	9
B240	76	373	Do.	5	B292	66	307	Do.	5
B241	77	352	Do.	5	B293	86	492	Do.	6
B242	75	278	Do.	4	B294	70	294	3/20/51	4
B243	89	468	Do.	5	B295	55	251	Do.	5
B244	61	222	Do.	4	B296	89	375	3/21/51	4
B245	63	203	1/31/51	3	B297	77	384	Do.	5
B246	87	373	Do.	4	B298	64	269	3/22/51	4
B247	81	438	2/2/51	5	B299	47	163	Do.	3
B248	86	440	Do.	5	B300	72	265	3/26/51	4
B249	89	415	Do.	5	B301	81	389	Do.	5
B250	80	419	Do.	5	B302	85	386	Do.	5
B251	29	67	Do.	2	B303	72	294	Do.	4
B252	80	328	2/7/51	4	B304	65	226	Do.	3

Table A.--Data on ovaries collected in Hawaiian waters--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3	Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3
B305	88	485	3/26/51	6	B357	62	269	5/7/51	4
B306	76	282	3/27/51	4	B358	73	347	Do.	5
B307	36	135	Do.	4	B359	81	493	Do.	6
B308	85	479	Do.	6	B360	62	244	Do.	4
B309	66	359	3/29/51	5	B361	93	348	Do.	4
B310	77	550	4/2/51	7	B362	54	359	Do.	7
B311	65	269	Do.	4	B363	51	233	5/9/51	5
B312	114	885	4/3/51	8	B364	71	433	5/10/51	6
B313	97	490	Do.	5	B365	67	292	Do.	4
B314	98	560	Do.	6	B366	39	130	Do.	3
B315	54	225	4/4/51	4	B367	70	306	Do.	4
B316	41	115	Do.	3	B368	84	431	5/14/51	5
B317	23	6	Do.	0	B369	83	673	Do.	8
B318	103	477	4/5/51	5	B370	91	485	Do.	5
B319	77	266	Do.	3	B371	70	295	5/15/51	4
B320	45	286	Do.	6	B372	114	756	Do.	7
B321	46	169	Do.	4	B373	74	296	Do.	4
B322	63	338	4/10/51	5	B374	48	297	5/16/51	6
B323	81	441	Do.	5	B375	69	302	Do.	4
B324	51	322	Do.	6	B376	40	132	Do.	3
B325	78	485	Do.	6	B377	44	182	5/17/51	4
B326	50	238	4/11/51	5	B378	81	506	5/21/51	6
B327	91	346	Do.	4	B379	83	1140	Do.	14
B328	76	423	Do.	6	B380	83	412	Do.	5
B329	45	233	4/12/51	5	B381	97	687	Do.	7
B330	55	216	Do.	4	B382	96	1170	5/22/51	18
B331	87	371	4/16/51	4	B383	98	665	Do.	7
B332	72	279	Do.	4	B384	63	408	Do.	6
B333	62	272	4/17/51	4	B385	86	592	5/23/51	7
B334	70	286	Do.	4	B386	91	466	5/28/51	5
B335	76	333	4/18/51	4	B387	73	702	5/29/51	10
B336	72	379	4/19/51	5	B388	73	376	Do.	5
B337	64	297	Do.	5	B389	104	1065	5/31/51	10
B338	83	450	4/24/51	5	B390	68	556	Do.	8
B339	48	323	Do.	7	B391	79	567	Do.	7
B340	55	230	Do.	4	B392	82	323	6/6/51	4
B341	55	284	Do.	5	B393	76	733	Do.	10
B342	78	889	Do.	11	B394	87	515	Do.	6
B343	56	278	4/25/51	5	B395	70	534	Do.	8
B344	69	273	Do.	4	B396	101	565	6/7/51	6
B345	28	82	Do.	3	B397	57	467	Do.	8
B346	83	367	Do.	4	B398	58	286	Do.	5
B347	73	367	4/30/51	5	B399	43	119	Do.	3
B348	44	368	Do.	8	B400	54	320	Do.	6
B349	25	66	Do.	3	B401	79	512	Do.	6
B350	75	440	5/1/51	6	B402	73	575	Do.	8
B351	51	249	Do.	5	B403	43	206	6/13/51	5
B352	68	318	5/2/51	5	B404	76	473	Do.	6
B353	71	605	Do.	9	B405	78	452	6/18/51	6
B354	65	338	Do.	5	B406	45	210	Do.	5
B355	83	497	5/3/51	6	B407	53	188	6/21/51	4
B356	54	296	Do.	5	B408	88	541	6/25/51	6

Table A.--Data on ovaries collected in Hawaiian waters--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3	Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3
B409	54	248	6/25/51	5	B457	72	336	8/28/51	5
B410	89	649	6/26/51	7	B458	53	227	Do.	4
B411	72	622	6/27/51	9	B459	85	341	Do.	4
B412	54	214	6/28/51	4	B460	54	280	8/29/51	5
B413	120	843	Do.	7	B461	73	369	8/30/51	5
B414	95	578	7/2/51	6	B462	57	225	8/31/51	4
B415	44	188	7/3/51	4	B463	63	325	Do.	5
B416	56	402	Do.	7	B464	85	626	Do.	7
B417	59	250	7/6/51	4	B465	50	244	9/4/51	5
B418	70	411	Do.	6	B466	69	381	9/5/51	6
B419	93	754	Do.	8	B467	78	364	9/7/51	5
B420	72	447	Do.	6	B468	57	194	Do.	3
B421	79	522	7/9/51	7	B469	83	304	Do.	4
B422	79	356	Do.	5	B470	98	579	9/11/51	6
B423	87	355	Do.	4	B471	88	871	9/17/51	10
B424	76	371	Do.	5	B472	88	1685	9/19/51	19
B425	94	396	Do.	4	B473	73	339	Do.	5
B426	71	335	Do.	5	B474	102	664	9/20/51	7
B427	74	382	Do.	5	B475	59	420	9/21/51	7
B428	84	743	Do.	9	B476	74	369	9/24/51	5
B429	79	891	7/10/51	11	B477	64	268	Do.	4
B430	51	207	Do.	5	B478	90	486	9/26/51	5
B431	79	370	Do.	5	B479	55	228	Do.	4
B432	70	581	Do.	8	B480	71	266	9/27/51	4
B433	60	304	7/11/51	5	B481	64	288	9/28/51	4
B434	54	318	Do.	6	B482	133	1028	Do.	8
B435	67	543	7/12/51	8	B483	76	355	10/4/51	5
B436	63	321	Do.	5	B484	49	284	10/5/51	6
B437	103	739	7/13/51	7	B485	127	609	10/8/51	5
B438	90	652	Do.	7	B486	103	460	10/9/51	4
B439	93	786	Do.	8	B487	50	179	Do.	4
B440	69	476	Do.	7	B488	83	446	Do.	5
B441	47	143	7/17/51	3	B489	67	275	10/10/51	4
B442	74	360	7/25/51	5	B490	36	192	10/11/51	5
B443	60	514	Do.	9	B491	59	243	10/12/51	4
B444	94	604	7/30/51	6	B492	60	305	10/16/51	5
B445	80	529	8/3/51	7	B493	40	112	Do.	3
B446	80	460	8/6/51	6	B494	96	670	10/18/51	7
B447	103	597	Do.	6	B495	71	377	10/19/51	5
B448	86	518	8/8/51	6	B496	95	644	Do.	7
B449	57	285	Do.	5	B497	85	440	10/25/51	5
B450	40	114	Do.	3	B498	82	412	10/30/51	5
B451	52	177	8/9/51	3	B499	76	407	10/31/51	5
B452	34	147	8/14/51	4	B500	88	380	11/2/51	4
B453	54	281	8/16/51	4	B501	73	299	11/5/51	4
B454	78	299	8/23/51	4	B502	78	243	11/6/51	3
B455	87	442	8/24/51	5	B503	76	410	11/7/51	5
B456	52	288	8/27/51	6					

1/ Examined for maturing eggs, maturing eggs present.

2/ Examined for maturing eggs, maturing eggs absent.

Table B.--Data on ovaries collected in the western equatorial Pacific

Ovary No.	Fish weight kg.	Ovary weight gm.	Relative ovary weight x 10^3	Date collected	Position	
					Latitude	Longitude
1000	43	1645	38	4/15/51	6°52'N	148°38'E
1001	48	1401	29	4/18/51	4°35'N	150°01'E
1002	39	1926	49	4/20/51	2°10'N	152°10'E
1003	57	1575	28	5/17/51	2°00'N	161°00'E
1004	51 [2/]	2001	39	5/13/51	1°55'N	160°53'E
1005	52 [2/]	1067	21	5/17/51	2°00'N	161°00'E
1006	39	825	21	5/28/51	1°15'N	160°30'E
1007	38	1165	31	4/24/51	1°48'N	152°50'E
1008	39	305	8	4/19/51	--	--
1009	39	991	25	5/21/51	4°52°N	158°15'E
1010	34	848	25	4/19/51	--	--
1011 [1/]	19	307	16	4/17/51	4°25'N	148°00'E
1012	44	693	16	5/14/51	1°30'N	161°50'E
1013	58	1445	25	5/27/51	3°40'N	158°02'E
1014	45	1208	27	5/23/51	4°45'N	163°00'E
1015	42	267	6	5/9/51	4°05'N	145°30'E
1016	43	923	21	5/23/51	4°45'N	163°00'E
1017	49	1365	28	5/23/51	6°45'N	160°00'E
1018	60	1610	27	4/26/51	3°20'N	152°50'E
1019	69	2605	38	5/23/51	4°45'N	163°00'E
1020	30	1173	39	4/27/51	2°05'N	153°30'E
1021	39	1094	28	5/21/51	4°52'N	158°16'E
1022	51	1293	25	5/13/51	1°55'N	160°53'E
1023	58	2024	35	4/16/51	5°20'N	147°50'E
1024	47	1181	25	4/14/51	1°40'N	160°45'E
1025	30	651	22	--	--	--
1026	48	1271	26	5/28/51	1°15'N	160°34'E
1027	51	1081	21	5/25/51	4°55'N	162°55'E
1028	45	1333	30	5/26/51	2°40'N	155°25'E
1029	68	1759	26	4/18/51	--	--
1030	64	1427	22	5/26/51	2°40'N	155°25'E
1031	64	2286	36	4/29/51	1°26'N	153°10'E
1032	88	2153	24	5/30/51	5°30'N	159°30'E
1033	68	1492	22	6/1/51	3°38'N	157°24'E
1034	38	801	21	5/23/51	4°45'N	163°00'E
1035	45	651	14	6/1/51	3°38'N	157°24'E
1036	30	268	9	6/5/51	1°28'N	154°22'E
1037	43	649	15	5/14/51	1°40'N	160°45'E
1038	--	458	--	3/30/51	--	--
1039	43	365	8	6/5/51	1°28'N	154°22'E
1040	45	331	7	4/2/51	--	--
1041	44	707	16	5/23/51	4°45'N	163°00'E
1042	32	1001	31	5/26/51	2°40'N	155°25'E
1043	26	184	7	6/7/51	2°20'N	154°25'E
1044	35	372	11	6/6/51	1°48'N	154°02'E
1045	39	767	20	5/28/51	1°15'N	160°30'E
1046 [1/]	14	29	2	5/27/51	3°40'N	158°02'E
1047	46	431	9	4/6/51	3°30'N	145°20'E
1048	61	762	12	5/31/51	4°18'N	160°40'E
1049	53	443	8	6/4/51	1°18'N	154°55'E
1050	42	505	12	4/28/51	--	--
1051	59	961	16	6/10/51	3°20'N	155°10'E

Table B.--Data on ovaries collected in the western equatorial Pacific--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Relative ovary weight x 10^3	Date collected	Position	
					Latitude	Longitude
1052	45	692	15	4/27/51	2°05'N	153°30'E
1053	24	262	11	5/2/51	1°30'N	156°00'E
1054	48	699	15	6/5/51	--	--
1055	69	622	9	5/13/51	1°55'N	160°53'E
1056	56	667	12	5/23/51	4°45'N	163°00'E
1057	40	480	12	5/30/51	5°15'N	163°55'E
1058	45	317	7	6/7/51	4°00'N	156°10'E
1059	52	2522	48	4/19/51	--	--
1060	79	3038	38	6/1/51	3°38'N	157°24'E
1061	68 2/	2793 3/	41	4/25/51	2°20'N	153°05'E
1062	56 2/	1784 3/	32	6/24/51	5°53'N	158°50'E
1063	39 2/	1460 3/	37	7/19/51	4°-5°N	167°-168°E
1064	22 2/	492 3/	22	6/25/51	2°-3°N	156°-157°E
1065	54 2/	562 3/	10	10/19/51	7°-10°N	178°-179°E
1066	98 2/	2634 3/	27	9/16/51	3°30'N	164°E
1067	32 2/	218 3/	7	9/29/51	3°-8°N	166°-171°E
1068	37 2/	874 3/	24	7/17/51	2°-3°N	166°-167°E
1069	37 2/	654 3/	18	10/19/51	7°-10°N	178°-179°E
1070	95 2/	2102 3/	22	7/27/51	4°-5°N	168°-169°E
1071	23 2/	100 3/	4	7/17/51	2°-3°N	166°-167°E
1072	56 2/	660 3/	12	8/30/51	4°30'N	155°00'E
1073	28 2/	442 3/	16	9/28/51	2°-4°N	163°-167°E
1074	--	408 3/	--	9/21/51	2°-7°N	160°-166°E
1075	28 2/	140 3/	5	7/19/51	3°-8°N	166°-171°E
1076	83 2/	2802 3/	34	8/12/51	6°15'N	173°E
1077	21 2/	112 3/	5	9/20/51	1°-4°N	165°-170°E
1078	39 2/	1060 3/	27	7/16/51	2°02'N	166°51'E
1079	53 2/	1006 3/	19	8/14/51	7°-8°N	173°-175°E
1080	91 2/	2256 3/	25	7/29/51	5°-6°N	168°-169°E
1081	112 2/	1614 3/	14	10/8/51	6°25'N	178°00'E
1082 1/	13 2/	32 3/	2	7/15/51	3°55'N	164°45'E
1083	85 2/	908 3/	11	10/17/51	7°-8°N	177°-179°E
1084 1/	16 2/	60 3/	4	9/23/51	2°-5°N	161°-164°E
1085 1/	19 2/	30 3/	2	10/19/51	6°-8°N	174°-179°E
1086	60 2/	1044 3/	17	10/19/51	7°-10°N	178°-179°E
1087	30 2/	466 3/	16	?/21/5/	2°-7°N	160°-166°E
1088	21 2/	268 3/	13	7/19/51	4°-5°N	167°-168°E
1089	43 2/	308 3/	7	9/29/51	3°-8°N	167°-171°E
1092	75 2/	1526 3/	20	?/4/51	4°-5°N	159°-160°E
1093	59 2/	1314 3/	22	10/19/51	7°-10°N	178°-179°E
1094	97 2/	3204 3/	33	10/15/51	6°-8°N	171°-172°E
1095	54 2/	2474 3/	46	9/13/51	2°59'N	161°47'E
1096	28 2/	536 3/	19	9/22/51	1°-6°N	163°-167°E
1097	38 2/	462 3/	12	9/24/51	2°34'N	166°15'E
1099	38 2/	476 3/	13	10/19/51	7°-10°N	178°-179°E
1101	20 2/	97 3/	5	9/22/51	1°-6°N	163°-167°E
1102	58 2/	1050 3/	18	10/19/51	7°-10°N	178°-179°E
1104	22 2/	120 3/	5	10/16/51	5°-7°N	176°-179°E
1105	25 2/	378 3/	15	10/19/51	5°-7°N	175°-177°E
1106	46 2/	324	7	9/24/51	?-5°N	163°-166°E

1/ Examined for maturing eggs, maturing eggs present.

2/ From length-weight relation, log weight = -7.1167 + 2.9304 log fork length. Relation calculated for bigeye of Hawaiian waters by POFI.

3/ Assumed that right ovary weight = left ovary weight.

Table C.--Data on ovaries collected in the central equatorial Pacific

Ovary No.	Fish weight kg.	Ovary weight gm.	Relative ovary weight $\times 10^3$	Date collected	Position	
					Latitude	Longitude
1	85	1598	19	9/18/51	2°02'N	153°01'W
2	76	1230	16	9/4/51	1°59'N	150°02'W
3	102	2130	21	9/16/51	1°54'N	156°10'W
4	86	2137	25	9/13/51	2°02'N	156°10'W
5	94	1073	11	9/4/51	1°59'N	150°02'W
6	68	1377	20	9/4/51	1°59'N	150°02'W
7	104	2979	28	9/13/51	2°02'N	156°10'W
8	91	2217	24	9/12/51	1°54'N	155°14'W
9	73	2177	30	8/24/51	14°44'N	150°08'W
11	86	2132	25	9/13/51	2°02'N	156°10'W
12	107	2048	19	9/16/51	1°54'N	156°10'W
13	70	1701	24	9/6/51	2°04'N	153°02'W
14	102	1785	17	9/2/51	3°58'N	150°00'W
15	89	2086	23	8/27/51	9°43'N	150°00'W
17	99	2261	23	9/18/51	2°02'N	153°01'W
18	70	2153	31	8/24/51	14°44'N	150°08'W
19	108	2404	22	8/25/51	11°35'N	149°57'W
20	54	1237	23	8/24/51	14°44'N	150°08'W
21	67	1348	20	9/5/51	1°54'N	155°14'W
22 [1]	68	2129	31	8/24/51	14°44'N	150°08'W
23 [1]	21	135	6	9/24/51	3°32'N	150°02'W
24	57	1442	25	8/24/51	14°44'N	150°08'W
26	52	683	13	8/25/51	1°35'N	149°57'W
27	85	774	9	8/31/51	5°58'N	149°55'W
28 [1]	64	1360	21	8/24/51	14°44'N	150°08'W
29 [1]	75	461	6	8/29/51	8°01'N	149°53'W
30	57 [3]	970	17	9/18/51	2°02'N	156°10'W
31	72 [3]	1597	22	8/23/52	5°16'N	140°28'W
32	81 [3]	1984	24	8/30/52	3°37'N	140°27'W
33	72 [3]	1726	24	8/23/52	5°16'N	140°28'W
34	93 [3]	2096	23	9/5/52	2°25'N	140°32'W
35	85 [3]	1239	15	9/6/52	2°06'N	140°56'W
36 [1]	85 [3]	567	7	9/4/52	3°201N	140°10'W
37 [1]	85 [3]	370	4	9/12/52	2°26'N	148°52'W
38 [1]	56 [3]	584	10	9/6/52	2°06'N	140°56'W
41 [1]	45 [3]	236	5	5/29/52	7°09'N	119°00'W
42 [1]	105 [3]	524	5	5/28/52	8°55'N	119°07'W
43	77 [3]	993	13	5/31/52	4°18'N	119°35'W
44	47 [3]	331	7	5/29/52	7°09'N	119°00'W
45 [1]	47 [3]	178	4	5/29/52	7°09'N	119°00'W
46	29 [3]	139	5	5/30/52	5°27'N	119°38'W
47 [1]	48 [3]	269	6	6/13/52	8°00'N	130°24'W
48	85 [3]	1837	22	6/13/52	8°00'N	130°24'W
51	90	2818	31	8/31/52	6°27'S	140°03'W
53 [1]	89	376	4	9/3/52	1°14'S	140°02'W
54 [1]	51	214	4	9/3/52	1°14'S	140°02'W
55	77 [3]	571 [4]	7	9/6/52	2°01'N	141°21'W
56	104	3732 [4]	36	9/1/52	4°51'S	140°09'W
57	96	4989	52	9/2/52	3°14'S	140°06'W
60	39 [3]	1268	32	2/2/52	2°46'N	155°11'W
61	51	359	7	1/29/52	8°02'N	154°58'W
62	--	1079	--	1/31/52	5°20'N	155°00'W

Table C.--Data on ovaries collected in the central equatorial Pacific--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Relative ovary weight x 10^3	Date collected	Position	
					Latitude	Longitude
63	65 3/	2351	36	2/2/52	2°46'N	155°11'W
64	45 3/	339	7	1/31/52	5°20'N	155°00'W
65	32 3/	232	7	1/31/52	5°20'N	155°00'W
70 2/	61 3/	224	4	1/26/53	15°46'N	154°13'W
71	64 3/	603	9	3/15/53	1°00'N	140°00'W
72	59	1402	24	3/6/53	10°09'S	144°31'W
73	79	552	7	3/13/53	1°00'S	140°05'W
74	84 3/	874	10	3/13/53	1°00'S	140°05'W
75	74 3/	835	11	2/12/53	1°13'S	150°03'W
76 1/	78 3/	648	8	2/12/53	1°13'S	150°03'W
77	41 3/	428	10	2/16/53	1°55'S	150°07'W
78	100 3/	1661	17	2/15/53	1°26'S	150°45'W
79	111 3/	2734	25	3/18/53	4°12'N	140°20'W
80	83	369	4	10/31/52	5°35'S	120°28'W
81	93	1083	12	11/2/52	9°39'S	120°47'W
82	64	330	5	11/6/52	3°14'S	130°19'W
83	66	274	4	11/9/52	1°11'N	130°23'W
90	73	1558	21	11/19/52	5°00'S	170°08'W
91 1/	99	557	6	10/19/52	17°22'N	156°21'W
92 1/	101	607	6	10/19/52	17°22'N	156°21'W
93	121 3/	3085	25	10/27/52	5°34'N	152°20'W
94	100 3/	2067	21	10/25/52	5°06'N	152°11'W
95	83	2669	32	10/29/52	3°13'N	152°05'W
100 1/	47	225	5	5/4/53	8°31'N	150°17'W
101 1/	50 3/	258	5	5/6/53	5°30'N	150°00'W
102	46 3/	307	7	6/8/53	6°13'N	170°07'W
103	40 3/	265	7	6/8/53	6°13'N	170°07'W
104	60 3/	670	11	6/8/53	6°13'N	170°07'W
110	47	1540	33	7/29/53	9°57'N	155°06'W
111	82	1657	20	7/29/53	9°57'N	155°06'W
112	59	1232	21	7/30/53	8°39'N	154°57'W
113 2/	28	77	3	7/31/53	7°15'N	155°04'W
114 1/	20	25	1	7/31/53	7°15'N	155°04'W
115	29	213	7	7/31/53	7°15'N	155°04'W
116	32	305	10	7/31/53	7°15'N	155°04'W
117	28 3/	207	7	7/31/53	7°15'N	155°04'W
118	42 3/	870	21	8/1/53	6°06'N	154°49'W
119	53 3/	835	16	8/1/53	6°06'N	154°49'W
120	97 3/	2000	21	8/1/53	6°06'N	154°49'W
121 1/	17 3/	94	6	8/5/53	2°02'N	156°13'W
122	102 3/	2295	22	8/26/53	7°50'N	159°24'W
123	66 3/	1075	16	8/27/53	4°43'N	160°00'W
124	74 3/	1645	22	8/26/53	7°50'N	159°44'W

1/ Examined for maturing eggs, maturing eggs present.

2/ Examined for maturing eggs, maturing eggs absent.

3/ From length-weight relation, log weight = -7.1167 + 2.9304 log fork length. Relation calculated for bigeye of Hawaiian waters by POFI.

4/ Assumed that right ovary weight = left ovary weight.